CONTENT-SENSITIVE SCREENING IN BLACK AND WHITE

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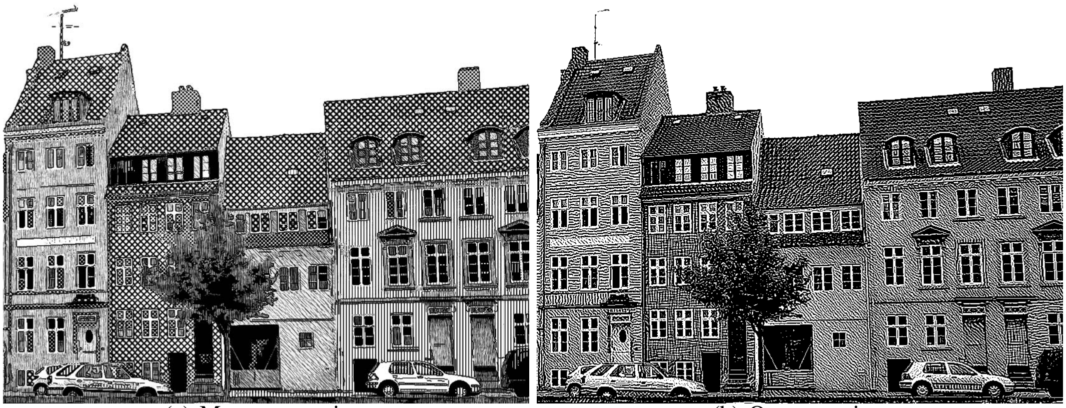
Abstract: Traditional methods produced unsatisfactory uniform screening. Often additional tones are added to improve the quality of tone and structure. In this paper, we try to produce screening with diverse patterns and with natural structure preservation while still using only one color of ink. We propose several extensions to contrast-aware halftoning including new weight distributions and variations on the priority-based scheme. Patterns can be generated by excluding pixels in a purposeful way and by organizing different groups of input edges based on user interest. Segmented regions are assigned different patterns, based on statistical measurements of the content of each region. Our method can automatically and efficiently produce effective screening with a lot of flexibility and without artifacts from segmentation or false edges.

1 INTRODUCTION

Screening in printing refers to a process of passing ink through a perforated screen (or pattern) over a region. Existing halftoning methods such as dithering methods (Knuth, 1987; Ostromoukhov et al., 1994; Ostromoukhov and Hersch, 1995b; Buchanan, 1996; Ulichney, 1998; Verevka and Buchanan, 1999; Veryovka and Buchanan, 2000) or hatching (Streit and Buchanan, 1998; Yano and Yamaguchi, 2005) usually generate uniform screening simply based on image tone without consideration of image contents. Though a wide variety of screens will definitely enrich visual effects, the question remains: how can different screens automatically support halftoning while still preserving tone and structure? Similar questions were asked since the beginning of screening (Ulichney, 1987). Artistic screening (Ostromoukhov and Hersch, 1995a) presented interesting effects. However, the good tone transition relied on both extremely large original images and low-pass filters without structure concerns. Recently some researchers (Ostromoukhov and Hersch, 1999; Rosin and Lai, 2010; Qu et al., 2008) abandoned solving this problem in binary images and instead introduced additional tones or colors. However, it is still worthwhile to address the black and white version of the problem for applications such as monochrome printing. Also an unfortunate aspect of recent methods is that image content preserved by segmentation methods or edge detection may possess serious artifacts or false edges.

Our motivation comes from recent structure-aware halftoning (Pang et al., 2008; Chang et al., 2009; Li and Mould, 2010) which produced excellent structure details. In particular, contrast-aware halftoning (Li and Mould, 2010) due to its priority-based scheme has a lot of potential for our problem. In this paper, we extend contrast-aware halftoning in the direction of nonuniform screening with natural looking structure details. We propose new weight distributions and introduce a multi-stage process for different groups of textural edges. Our pattern assignment is sensitive to the content of the image. Our contribution is an automatic method smoothly unifying different patterns with the image content. In Figure 1, our tree in front of the building is clearer than the result from the manga screening (Qu et al., 2008) and different patterns applied to the building's wall provide a rich viewing experience. Visually our result contains no segmentation artifacts, which are obvious in (a) despite the use of greyscale rather than a single tone.



(a) Manga screening (b) Our screening

Figure 1: Building.

2 PREVIOUS WORK

Screening is a special kind of halftoning with some control over patterns, which convey a given intensity in a block. The techniques include classic ordered dither algorithms (Ulichney, 1987), algorithms combined with error diffusion (Knuth, 1987), the variation of rotated dispersed dither (Ostromoukhov et al., 1994; Ostromoukhov and Hersch, 1995b), and aperiodic patterns of clustered dots (Velho and Gomes, 1991). Whether image-independent dithering or image-dependent, these methods share the same problem: the unsatisfactory uniform patterns. Only considering tone but ignoring structure preservation makes appearance unattractive. Subsequently, a lot of researchers have made tremendous effort in pattern generation to try to change the unappealing factors. Buchanan (Buchanan, 1996) introduced controlled artifacts with limited success. Ulichney (Ulichney, 1998) proposed a way for generating dither patterns by recursive tessellation but did not mention how to apply to an image in a unified way. Some procedural screening methods (Ostromoukhov and Hersch, 1995a) freely generated artistic screening elements with limited shapes. The smooth transition is a big problem, which they avoided in later work by adding more tones (Ostromoukhov and Hersch, 1999; Ostromoukhov, 2000). A more powerful way for different patterns is from image-based dither screens (Verevka and Buchanan, 1999; Veryovka and Buchanan, 2000; Yano and Yamaguchi, 2005). However, those improvements are still focused on tone matching.

In order to maintain image content, either sharpening (Velho and Gomes, 1991; Buchanan, 1996) or user-defined segmentation (Streit and Buchanan, 1998) can be employed. Recently, structure-aware screening (Qu et al., 2008) designed for manga effects proposed color to pattern ideas to connect the image content with patterns. This approach produces continuous-tone output, however, whereas we are concerned with binary output. Our goal is to propose an automatic method with flexibility to show different patterns and to naturally represent image content in black and white.

3 OUR METHOD

Contrast-aware halftoning (CAH) (Li and Mould, 2010) is a type of error diffusion method (Floyd and Steinberg, 1976) with two variations. First, it distributes error in a contrast-aware way. Second, it processes pixels in a priority-based order. Because the strategy respects the pixel's initial predisposition towards dark or light when distributing error, these two modifications guarantee good structure preservation. In order to adapt it to screening effects, we extend CAH in two ways: new weight distributions (exclusion-based masks) and new priority configuration (a multi-stage process).

3.1 OVERVIEW

Given an original image, our system first segments it into regions and calculates a gradient map. Then, the system assigns different screens for different regions. This is done by calculating how much sensitive content occupies each region. Different classifications are handled with different strategies to promote content. In the end, the system produces specific screening effects through contrast-aware halftoning with our new variations.

Segmentation is done using mean shift (Comaniciu and Meer, 2002). Oversegmentation will not have visible disadvantages for our final screening since our consideration of structure removes the artifacts based on the content of the original image. The segmentation is to guide the separation of content when making pattern assignments. The content-sensitive approach to assignment helps understand the image and further emphasizes structural details. As for pattern creation, either exclusion-based masks or the multi-stage process can provide ways for creating patterns. We put more effort on the former type since it is easy to control. In addition, users are still able to control interesting edges and the quality of tones by simply adjusting a few parameters.

3.2 PATTERN ASSIGNMENT

After we have the segmentation map and gradient map, we calculate how much of each region R_i is occupied by sensitive content. A statistical measurement H based on thresholding gradient magnitudes is computed as follows.

$$H_h = \frac{number(g(m,n) > T_h)}{N_{\in R_i}} \quad (1)$$

$$H_l = \frac{number(g(m,n) > T_l)}{N_{\in R_i}} \quad (2)$$

The gradient is written as $g(m,n)$ for the pixel at position (m,n) with intensity values $I(m,n)$. In Equation 1, H_h obtains the proportion of the pixels with high gradient magnitudes while in Equation 2, H_l obtains the percentage of the pixels with low gradient magnitudes, where T_h and T_l are thresholds holding $T_h \gg T_l$. The function $number(.)$ counts the number based on the given predicate. $N_{\in R_i}$ is the number of pixels in the region R_i. The examples shown in this paper usually use $T_h = 100$ and $T_l = 35$. The type of assignment is classified according to Equation 3.

$$C_i = \begin{cases} 0: Empty(white) & \text{if } H_l < r_l \text{ and } I(m,n) > W \\ 1: Low(yellow) & \text{if } H_l < r_l \text{ and } I(m,n) \leq W \\ 2: Medium(green) & \text{if } H_l \geq r_l \text{ and } H_h > r_h \\ 3: High(blue) & \text{otherwise.} \end{cases} \quad (3)$$

In the above, r_l and r_h are thresholds for ratio of sensitive content and W is a threshold for very light area. We use $r_l = 0.25$, $r_h = 0.6$, and $W = 200$ in this paper. This C_i allows us to classify each region. We employ different assignment strategies for different C_i. In this way, we stylize the image content.

1. If C_i is zero, this area (shown in white) might be background or trivial area. In order to satisfy the tone requirement, halftoning these kind of areas will use very few black pixels to represent those very light areas, which can be distracting. For those unimportant regions we leave them empty or use an arbitrary pattern to fill in.
2. If C_i is 1, it is a uniform region (shown in yellow) with medium intensity values. We can randomly assign the patterns. Since the contrast-aware strategy and the priority-based error diffusion preserve the structure and tone, the random assignment still promotes our quality.
3. If C_i is 2, it is a region (shown in green) having medium degree of content. We either match the pattern direction with the main direction of the region or use the edge-exclusion approach to match patterns with content.
4. The remaining regions (shown in red) have C_i equal to 3. These regions are highly textured and it is better to preserve all the information. In this case, we use basic contrast-aware halftoning without our variations, or combine it with edge-exclusion masks as described later.

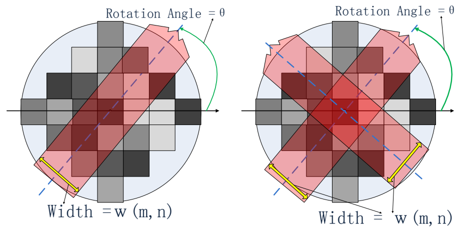
Figure 2 shows the segmentation and corresponding content-based classification according to this strategy. In Figure 2 (c), the blue regions show highly textured hair. Less textured regions are displayed in green. Other yellow regions mean there is not much change in content, so we consider them uniform regions.

(a) (b) (c)

Figure 2: Content-based assignment. (a) Original image; (b) Segmentation; (c) Our assignment.

3.3 PATTERN GENERATION

We propose two different ways to generate patterns. Type I controls the order of error diffusion in an organized way. Type II uses a multi-stage process to preserve edges from input images.



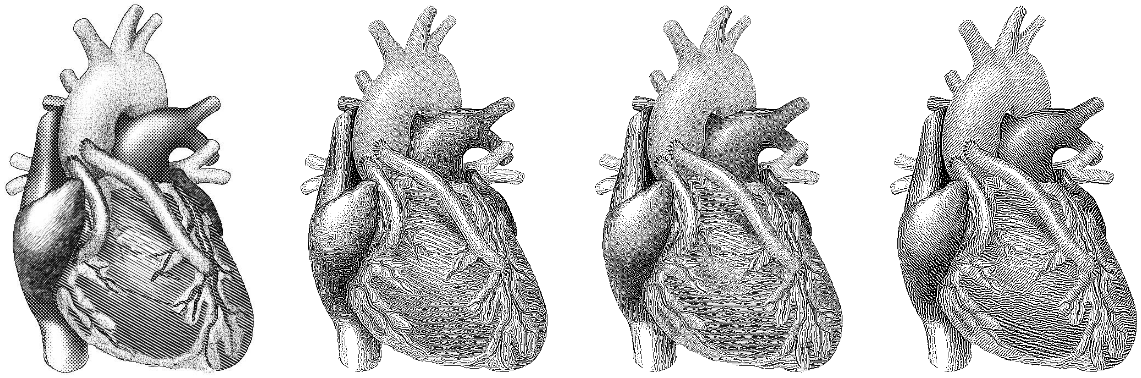
(a) (b)

Figure 3: Type I: Exclusion-based masks. (a) Exclude one direction; (b) Exclude two directions.

3.3.1 TYPE I: EXCLUSION-BASED MASKS

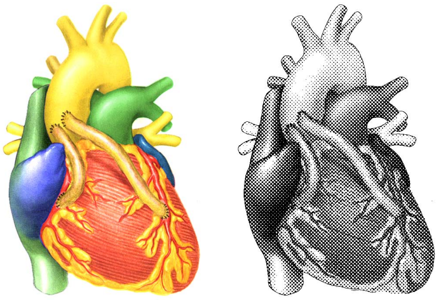
After each step of priority-based error diffusion, the pixels under the mask lower their priorities to maintain a good spatial distribution. Instead of processing all pixels in the mask, we exclude specific subsets of pixels. The excluded pixels will have unchanged priorities, thus promoting their chances to be chosen as the next pixels. In this way, we promote the formation of interesting patterns.

Figure 3 shows two designs for creating this kind of patterns. The first shown in (a) is to cover the pixels under a direction with angle θ and with width $w(m,n)$ within a mask. This way can represent horizontal, vertical, or other directional patterns. For example, suppose that horizontal exclusion is chosen. After each error diffusion step, the pixels under the horizontal lines are not affected thus do not change their original priorities. In this way, the horizontal lines



(a) (b) (c) (d)

Figure 5: Comparisons. (a) Manga screening (greyscale); (b) $C_i = 2$ with edge-exclusion masks; (c) $C_i = 2$ with main direction; (d) Thicker version of (c).



(a) Original image (b) Dithering

Figure 4: A heart.

create a pattern. We also propose an edge-based exclusion mask, which excludes the pixels on the direction of edge tangent along the center pixel. This edge-oriented weight distribution enhances structures; we use it for regions with $C_i = 3$ to preserve highly textured regions or sometimes for regions with $C_i = 2$. Another way for regions with $C_i = 2$ is to use the main direction of the region to guide the rotation angle θ.

Similarly, in Figure 3 (b), the pixels under a circular mask are covered with two directions of strips, also along with parameters θ and $w(m,n)$. This can provide crossed patterns.

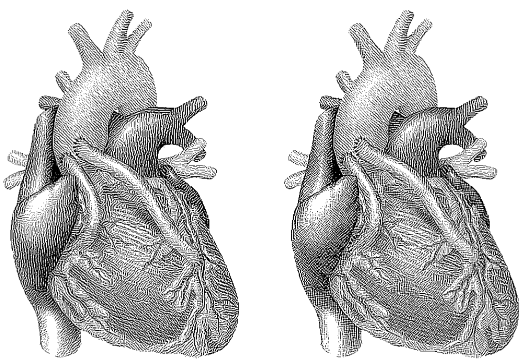


Figure 6: Thickness control. Left: 4 patterns; Right: 6 patterns.

Figure 5 shows the method applied to a heart image. Compared with dithering shown in Figure 4 (b), our results are non-uniform and look much better. Also compared with manga screening, even though we are using only black and white, not greyscale, even the small veins are very clear. We can also control the thickness of the exclusion width. We calculate thickness $w(m,n)$ as follows;

$$w(m,n) = MAX \times (1 - I(m,n)/255) \quad (4)$$

where MAX is the maximum thickness: we use 6 here. A different heart example appears in Figure 6, showing thickness control for different patterns. Both enhance the pattern effects without losing structure details. For tone we show a ramp in Figure 7 for some patterns. Visually, they are reasonably continuous and able to convey tone differences.

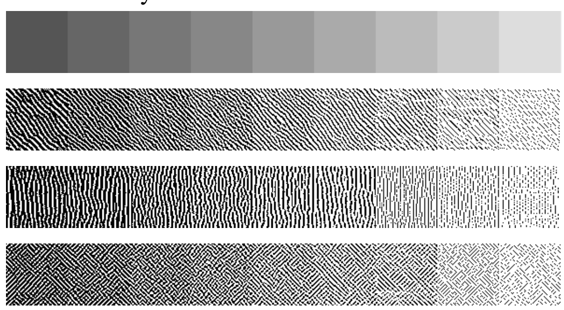


Figure 7: Ramp with different patterns.

Edge-exclusion masks and main directions: Generally, the results from edge exclusion are more appealing than the method using only the main direction. Figure 5 and Figure 8 show the difference between exclusion-based masks and main directions. Visually, both preserve structure details quite well.

(a) Main direction (b) Edge exclusion

Figure 8: Content-sensitive assignment.

3.3.2 TYPE II: A MULTI-STAGE PROCESS

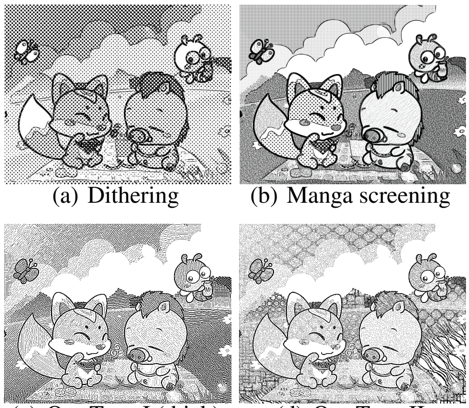
The priority-based scheme provides good flexibility for promoting edges: we can vary our priority configuration guided by edges. Edge pixels will be processed first, which increases the chance of those pixels being chosen. It lowers the influence from the remaining pixels. If there are different types of edges to be promoted, the process is separated into several stages. Through this process, the patterns from input textures can be easily adapted. Since the existing texture is in a very wide range, the content-sensitive strategy cannot play a large role. Figure 9 and Figure 10 show some variations based on different assignment and different texture inputs. They give diverse effects considering both tone and structure.

Figure 9: Type II patterns for building.

4 RESULTS AND DISCUSSION

Our method is automatic. Previous methods such as manga screening (Qu et al., 2008) will manually regroup small regions to avoid fragile output. Since the small regions will not destroy our quality, we can skip this step and hence save time. Our assignment is not treated as a colorization problem. We let the intrinsic tone and content guide the patterns, which saves further time. Based on an Intel Core Duo CPU E8400@ 3.0GHz with 3GB RAM and processing 800 × 1000 image, including the segmentation time (72 seconds), it takes 110 seconds to gain our results, which is faster than the four minutes needed by manga screening in the same situation. Excluding segmentation time, our process only takes a few seconds to tens of seconds.

A comparison is shown in Figure 12. It is clear that our results are much better than dithering. Manga screening places the segmentation boundaries on top of patterns to distinguish objects. They have man-made edges between cloth and the desktop, and annoying boundaries between objects on the desk, which looks unnatural. Our results avoid segmentation artifacts. Our structure details are gracefully preserved by contrast-aware masks and priority-based scheme with promotion from content-sensitive assignment. Further, the edge-exclusion mechanism and main direction grasped for medium sensitive content give another promotion for structural contents. Another comparison is shown in Figure 10.



(a) Dithering (b) Manga screening

(c) Our Type I (thick) (d) Our Type II

Figure 10: More comparisons.

Figure 11 shows that our scheme is also open to color extension. It uses different textures as input patterns. It gives us interesting and distinct effects, though not as yet fully explored.

Figure 11: Extension to colored screening.

5 CONCLUSIONS

In this paper, we demonstrate the possibility to show different screening patterns in black and white with good structure details. Our ideas for exclusion-based masks and the multi-stage process can be adapted to a lot of applications in image processing or non-photorealistic rendering. As for future work, we should refine the content-based assignment for patterns and improve the multi-stage process. Color halftoning with color harmonization for screening will be a very interesting direction too.

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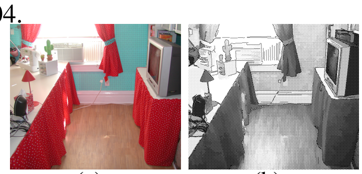
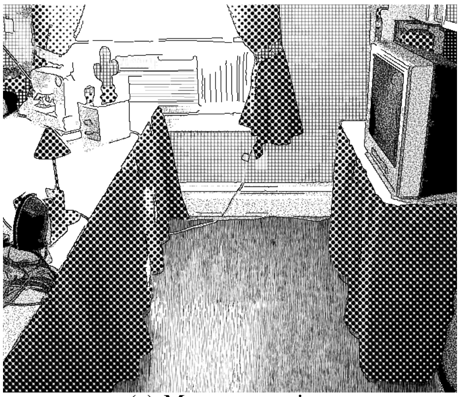
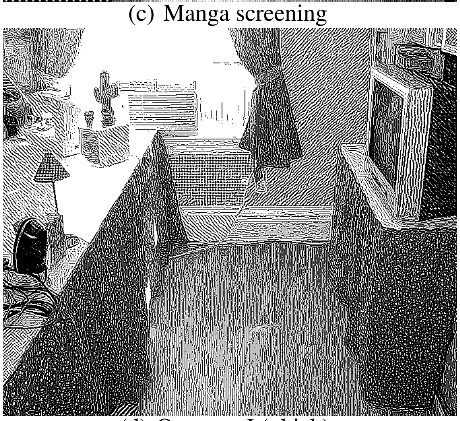


(a) (b)



(c) Manga screening



(d) Our type I (thick)

Figure 12: More comparisons. (a) Original image; (b) dithering.

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