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Contrast brushes: interactive image enhancement by direct manipulation

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Abstract

We implement contrast brushes, an interactive method for directly brushing contrast adjustments onto an image. The adjustments are performed by a histogram warping approach that implements tone mapping using piecewise-defined, continuously differentiable, monotonic splines. This allows the independent specification of tone changes and contrast adjustments without causing halo or contouring artifacts, while still endowing contrast brushes with intelligible parameters that render their effects predictable for the user. A user study demonstrates that contrast brushes can prove more effective than Adobe Photoshop's interactive contrast enhancement tools.

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [Models and Principles]: Human factors I.4.3 [Image Processing and Computer Vision]: Filtering

1. Introduction

Contrast is an organising principle of visual communication. For the viewer, contrast attracts attention; for the artist, contrast conveys emphasis. In graphic design, contrast is used to tell the eye where to go. When presenting information, contrast makes the composition legible. When a picture carries the message, contrast can be applied to underline it. In imaging, contrast reflects a necessary compromise, since the human visual system accommodates a dynamic range that is several orders of magnitude greater than the ones available to image reproduction systems.

It is, therefore, unsurprising that many computerised image processing tasks involve contrast adjustment. It is, however, surprising how contrast adjustment is performed. A typical user interface is shown in Figure 1. Users are presented with a bewildering array of text boxes and sliders to specify, manually, the defining properties of an image transformation curve. They interact with a complex abstract entity rather than the image itself and somehow infer the effects of this on the image. Such an approach is inappropriate for ordinary users, though trained experts are able to get good results. Traditional photography relies on an even more difficult "user interface" for contrast adjustment. For example, the expert photographer Ansel Adams developed methods for selectively overexposing and underexposing the print by waving cardboard cutouts over portions of the print during exposure [AB83]. Modern image processing offers effective region selection and feathering tools, and even simulates Adams' methods in *dodge* and *burn* tools [RSSF02]. However, interactive contrast adjustment remains a needlessly cumbersome task.

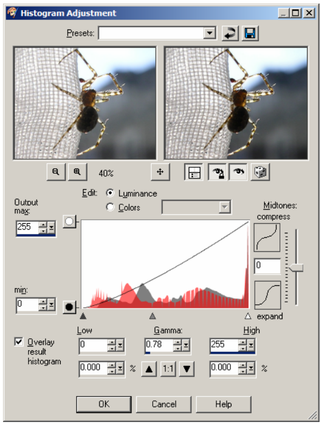

Figure 1: *The histogram adjustment tool in Jasc® Paint Shop Pro^{TM}.*

Our aim is to provide a simple, flexible interactive method

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for specifying local contrast adjustments. It builds on our work on interactive global contrast enhancement [GD04b] and uses our histogram warping technique [GD05, GD04a].

2. Motivating example

Consider a bland image of a ferry at sea (Figure 2(a)). Contrast enhancement could be used to make the sky appear calm (low contrast) or stormy (high contrast). As an example, we wish to manipulate the tepid, low contrast original into an intrepid boat sailing against a dark and brooding sky. Fully automated histogram equalisation produces a suitably ferocious sky (Figure 2(b)). But the ferry's texture is over-exaggerated. Indeed, in images with narrow histograms and relatively few grey levels, increasing dynamic range normally has the adverse effect of increasing visual graininess and patchiness [GW02]. Histogram equalisation does not provide the control we want. The histogram adjustment tool of Figure 1 allows us to achieve the desired sky without introducing noise on the ferry (Figure 2(c)). Our global, interactive, non-adaptive histogram warping technique [GD04b] produces similar results using a histogram warping approach. The user specifies a tone mapping function by simply clicking on the image: the mouse pointer selects the tone, the mouse button decides whether its contrast is raised or lowered, and the mouse wheel can control the degree of contrast adjustment as desired. There is thus direct interaction with the image, unlike histogram equalisation and commercially-available histogram adjustment tools.

A critical constraint is that there is a fixed contrast budget: increasing contrast in one part of the range forces a decrease in contrast elsewhere. For instance, enhancing the mid-tones requires de-enhancing the highlights and shadows. This is a problem because the global methods do not adapt to local image features. Contrast should not be enhanced indiscriminately, as the same tones play different roles in the interpretation of different aspects of the image. For instance, for selective emphasis, it may be desirable to raise a particular tone's contrast in the foreground without the distraction of raising its contrast in the background. Figure 2(c) shows this effect: the same transformation that enhances the sky darkens the ferry and removes detail from the water. In practice, users often need to apply a tone, lightness or contrast alteration locally to a selected area of the image.

We could solve the problem by using either a localised method or an adaptive method. A localised method can be used multiple times with different transformations for different image regions such as sky, ferry and water. We report on such a method here. A sufficiently clever adaptive method might vary the transformation across the image as directed by the user or an automatic algorithm. Localised methods are preferable because adaptive methods risk taking too much control away from the user. This is especially relevant when image interpretation is ambiguous, as is the case with the ferry.

It is, of course, possible to produce local adjustments with the tools available in commercial packages: the user specifies a region of the image on which the global tool should be applied. This, indeed, seems to be the preferred way of working for the professional. It allows multiple layers of adjustments which can be revisited and reworked repeatedly until the correct result is achieved. The limitation of this is that the image adjustment tool is not integrated with the image selection tools. The user must explicitly select an area of the image before switching tools to apply the desired operation, and they therefore lose the immediate feedback of direct manipulation. The amateur may prefer a more direct method.

We therefore investigated whether our histogram warping technique could be used effectively to provide localised, direct manipulation of contrast. We implemented this and undertook a user study to compare it against the commercial state-of-the-art. The ferry image, enhanced using our tool, can be seen in Figure 2(d). The sky is dramatic, as in the results of histogram equalisation and histogram adjustment. However, the ferry was also brightened to appear triumphant and the dynamic range of the waves was expanded to capture their detail. Notice that there are no contrast artifacts along the hull. The opportunity to use artistic license was exploited and the area surrounding the flag was brightened, creating a focal point for the eye.

3. Related Work

In image enhancement for visual inspection [GW02, Zam95], the role of user interaction in contrast adjustment has received surprisingly little attention. Aside from the numerous automatic algorithms, there are three broad approaches for interactively specifying grey level transformations.

The transformation may be defined indirectly through histogram specification [GW02,Hum75,GF77,OB85]. The user is still faced with the dilemma of selecting the correct histogram for the image. Without taking into account the original histogram, forcing the image to conform to an arbitrary histogram can yield unpredictable results since it is difficult to foresee how much distortion the transformation entails. Moreover, the relationship between the shape of a histogram and the relative contrast of an image may not be readily apparent to an untrained user. A histogram that appears ideal for one image can prove unsuitable for another despite any similarities between the two pictures. In an interactive tool, the user can control histogram specification by selecting a region of interest [SVO*90]. Only at most the first three statistical moments of the histogram have been shown to predictably affect contrast [TG83]. A flat histogram maximises the entropy of the encoded information while a hyperbolic histogram maximises the entropy of the perceived brightness [Fre77]. As Gonzalez and Woods [GW02] observe, "in general... there are no rules for specifying histograms."

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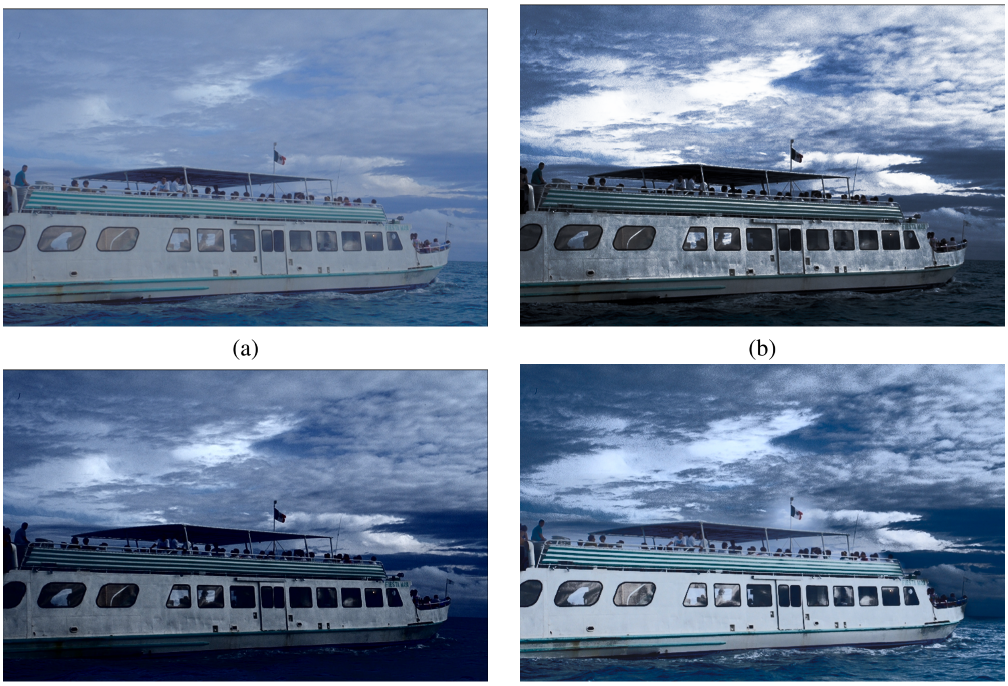

(a) (b) (c) (d)

Figure 2: *An image of a ferry is adjusted in three ways. (a) Original. (b) Histogram equalisation. (c) Manual global adjustment using Paint Shop Pro. (d) Manual local adjustment using contrast brushes.*

Alternatively, the grey level transformation may be expressed directly by a mathematical function, $y = T(x)$ with its parameters chosen by the user. Since reversing image polarity is not normally desirable, a monotonic increasing transformation, $T'(x) \geq 0$, is required to preserve the natural order of grey levels. Since abrupt transitions between differing degrees of stretching and compression of the tonal range can cause visible defects, a continuously differentiable C^1 transformation is required to avoid artificial discontinuities in the new histogram. Our histogram warping technique uses splines designed to meet these two requirements. Previously, contrast enhancement has been performed by linear [GW02, Zam95, XM02], quadratic [Guo91], cubic [OB85, Guo91], power law [GW02, Zam95], sigmoidal [Zam95, SL98, BF99], logarithmic [SL98, GW02], exponential [SL98], and regularised incomplete beta [Tub87, SL98] functions. Different functions can be always combined using a weighted average [SL98], though the resulting transformation may prove difficult to parametrise intelligibly. Default parameters may be obtained by the optimisation of an image quality criterion [SL98, XM02] or through the study of user preference [BF99]. These simple formulae lack the necessary degrees of freedom to express simultaneous and independent contrast adjustments at different points in the tonal range. Piecewise defined functions can cope with this challenge. Existing implementations fail to meet our requirements, as piecewise exponential [RTP*98] and piecewise linear [GW02, KHCP99] histogram transformations are not continuously differentiable while cubic splines [OB85] can cease to be monotonic in regions of heightened contrast.

Although there exist more flexible interactive techniques for histogram modification, they are not necessarily easy to control. Existing image processing packages, such as Adobe Photoshop, invite the user literally to draw the grey level transformation curve. As the shape of the curve changes both tone and contrast at the same time, such a user interface demands considerable skill and practice. Instead of focusing on getting the image right, the user must pay attention to getting the curve right. Using design galleries [MAB*97] or interactive evolution by aesthetic selection [Sim93] to explore the parameter space [HHKP96] of grey level transformations is a plausible alternative, although these approaches to user interaction are usually reserved for applications where direct manipulation does not suffice.

There also exist methods for interactively defining the mask on which a contrast adjustment is performed. Of particular note is Lischinski et al's method [LFUS06], which is inspired by the same observations as ours. Their method uses brushstrokes to select exemplars that are then propagated to produce regions of similar luminance. While superficially

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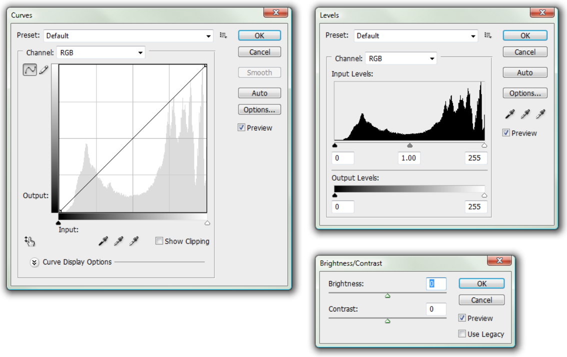

Figure 3: *The adjustment dialog boxes from Adobe®Photoshop®CS4.*

similar to our method, Lischinski's brushstrokes generate a set of masks on which operations are performed; whereas our method takes a defined operation and allows the user to brush it onto the image. In effect, our method provides the fine control that a graphic artist is likely appreciate when trying to make a picture look its best. We do not seek to replace region selection or image segmentation. Image editing programs already have separate tools dedicated to this purpose. In the context of a full featured image editor, the user will have the option either to apply contrast brushes in an unconstrained manner or to select first the region of interest and then apply contrast brushes so that they are constrained to alter only the selected region and leave the rest of the picture unaffected.

4. The state of the art

The state of the art for localised interactive contrast and lightness adjustment is taken to be Adobe® Photoshop®. To have another yardstick, we also considered Photoshop's main competitor in the amateur market: Jasc®Paint Shop Pro™. The relevant facilities are almost identical between the two, and we concentrate on Photoshop, which was used in our user study.

Photoshop offers three dialog boxes (Figure 3) to define transformation curves: *Curves*, *Levels* and *Brightness/Contrast*. The details are unimportant but an appreciation of what they achieve is useful. All three dialogs can specify contrast and lightness adjustment.

Curves. The user directly defines a transformation curve by drawing it or by manipulating control points. The user must understand transformation curves. This dialog is the hardest to use but the most flexible.

Levels. The user controls a gamma transformation with five degrees of freedom by adjusting sliders for the input black and white points, gamma adjustment and output levels.

Brightness/Contrast. The user defines a transformation curve by adjusting sliders for brightness and contrast. This dialog is the easiest to use but least flexible.

Photoshop and Paint Shop Pro use adjustment layers to localise contrast and lightness adjustment. An adjustment layer is an image mask with an associated transformation. They both also provide dodge and burn brushes which locally adjust lightness without needing an adjustment layer.

5. Histogram warping technique

Our histogram warping technique [GD04a,GD04b,GD05] is founded on the observation that there are two basic requirements for piecewise defined tone mapping functions. Since reversing image polarity can cause halo artifacts in smooth gradients (Figure 4(a)), a monotonic increasing transformation is required to preserve the natural order of tones. Since abrupt transitions between differing degrees of stretching and compression of the tone range can cause contouring artifacts in smooth gradients (Figure 4(c)), a continuously differentiable transformation is required to ensure that tones and contrast are altered in a smooth and seamless manner. As previously proposed for use in histogram modification, piecewise cubic splines can fail to be monotonic [OB85] while piecewise exponential splines can fail to be continuously differentiable [RTP*98]. Our histogram warping method is designed to resolve these deficiencies.

A key advantage of our technique is that it reshapes histograms in a continuous fashion, ensuring that the transformation preserves the continuity of the histogram, unlike most previously proposed, piecewise defined, histogram transformations [Pel78, RD78, DJT92, YT97, YHH-SKSBD98, RTP*98, WKC*98, KHCP99, YQB99, SDR03a, SDR03b].

We have designed our histogram warping technique to be a general method for formulating colour and tone mapping functions. The histogram warping transformation is controlled by defining its effect on a set of key tones, with its displacement determining the tone shift and its slope determining the contrast adjustment. The transformation $y = T(x)$ is specified by the mapping of corresponding key tone values $b_k = T(a_k)$ along with their contrast adjustments $d_k = T'(a_k)$. Thus, it provides simultaneous control over the output tones, b_k, and contrast adjustments, d_k, making it possible to alter tone and contrast independently. In this way, it is possible to separately control how shifting the histogram changes tones, $a_k \neq b_k$; how stretching the histogram raises contrast, $d_k > 1$; and how compressing the histogram lowers contrast, $0 \leq d_k < 1$. The influence of each tone shift, $b_k = T(a_k)$, and contrast adjustment, $d_k = T'(a_k)$, extends only as far as the adjoining key tones, $x \in [a_{k-1}, a_{k+1}]$. Our only constraint is that the parameters must describe a valid monotonic function, where the input key tones are strictly increasing, $a_{k-1} < a_k$, the output key tones are increasing, $b_{k-1} \leq b_k$, and the contrast adjustments are non-negative and finite, $0 \leq d_k < \infty$.

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

Figure 4: *Examples of common artifacts produced by tone mapping functions. Each image has its tone mapping curve in the top right corner. (a) A C^1 cubic spline producing a halo artifact because it has inverted the normal order of tones in a part of the luminance range. (b) Our C^1 monotonic rational spline prevents halo artifacts from occurring. (c) A C^0 linear spline produces contouring artifacts. (d) Our C^1 monotonic rational spline avoids undesirable contouring artifacts.*

Histogram warping uses an interpolating spline that is piecewise defined, monotonically increasing and continuously differentiable. Piecewise defined transformations ensure that the tone mapping can be changed locally without unintended global effects. Monotonically increasing transformations preserve tone ordering and thus avoid halo artifacts caused by reversals of image polarity (Figure 4(a)). Moreover, they are numerically invertible, making it possible to reverse the effect of any transformation. Continuous transformations avoid abrupt changes in tone that can create false contours in homogeneous image regions. Continuously differentiable transformations (Figure 4(c)) avoid abrupt changes in contrast that can create false contours in smooth image gradients. In effect, a continuously differentiable, transformation refrains from introducing artificial discontinuities into the resulting tone histogram. Finally, it should be possible to locally perform an identity transformation, by setting $b_{k-1} = a_{k-1}$, $b_k = a_k$, $d_{k-1} = 1$, and $d_k = 1$. To satisfy these requirements in a computationally efficient way, the histogram warping transformation $T(x)$ relies on a piecewise rational quadratic interpolating spline [GD82, SAMA97]:

$$T(x) = b_{k-1} + \frac{r_k t^2 + d_{k-1}(1-t)t}{r_k + (d_k + d_{k-1} - 2r_k)(1-t)t}(b_k - b_{k-1})$$

$$\text{where } r_k = \frac{b_k - b_{k-1}}{a_k - a_{k-1}} \text{ and } t = \frac{x - a_{k-1}}{a_k - a_{k-1}} \text{ for } x \in [a_{k-1}, a_k]$$

Observe that the transformation $T(x)$ is continuous and strictly monotonic while its derivative $T'(x)$ is continuous and positive when all $d_k > 0$. In a practical implementation, $T(x)$ can be used to create a lookup table, mapping x to $T(x)$, where $x \in [0, 255]$ for 8-bit images, for example.

6. Contrast brushes

Contrast brushes integrate, in a single tool, region selection and contrast adjustment (Figure 6). Just as normal colour brushes serve as a natural interface for painting an image, contrast brushes offer a simple, flexible interface for transforming an image. They locally alter the lightness and contrast of an image. They operate on the luminance channel in the *Lab* colour space. This keeps the chrominance constant but can potentially map some colours out of gamut. There are many possible gamut mapping solutions; for example, one may efficiently implement tone mapping directly in the RGB and CMY colour spaces while guaranteeing the hue is preserved [NM03].

Contrast brushes allow the user to configure the parameters of the desired transformation and immediately preview its effects. The user applies the transformation as a brush stroke made by dragging the mouse over the desired area of the image. If one brush stroke is insufficient to cover the desired region, the same transformation can be applied again by making another brush stroke. Depending on which mouse button is pressed, the effect can be made cumulative. A soft brush allows the user to reduce the effect of the transformation applied with each brush stroke, so that precise and subtle changes can be achieved through the accumulation of several brush strokes. The user can adjust the size of the brush to control the size of the area affected by the operation. The user can also select a feathered brush that enables the transformed area to blend smoothly with its surroundings. The parameters of the transformation can be tuned using two different approaches. A slider interface (Figure 6 bottom) shows the shape and effect of the current transformation spline while its parameters are specified by dragging the interface controls and selecting the image tones. A variations interface (Figure 6 top) displays previews of the effects of possible changes to the transformation while its parameters are adjusted by selecting the desired previews. The former tends towards the user interface of Photoshop *Levels* dialog box (Figure 3); the latter towards the design galleries approach [MAB*97].

To implement contrast brushes, we applied histogram

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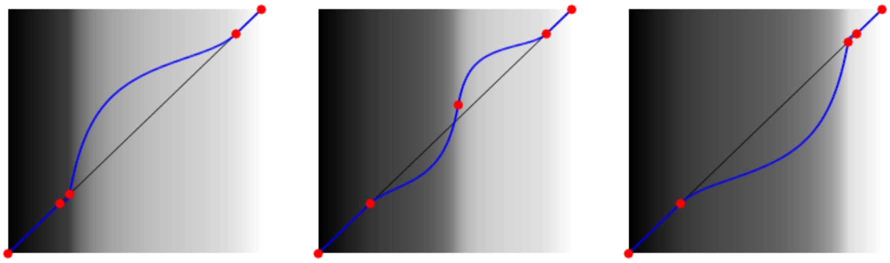

(a) (b) (c)

Figure 5: *Histogram warping transformations used for contrast enhancement with contrast brushes. (a) Gamma type transformation raises shadow contrast by lowering highlight contrast. (b) Sigmoid type transformation raises mid-tone contrast by lowering shadow and highlight contrast. (c) Gamma type transformation raises highlight contrast by lowering shadow contrast.*

warping to model a large family of commonly used operations for interactive image enhancement, based on the traditional notions of shadows, mid-tones and highlights. A typical task of contrast enhancement is to adjust the tone and contrast of mid-tones. Such transformations are situated in the dynamic range by the low tone of the shadows and high tone of the highlights. Their effects are specified by the tone shift and contrast adjustment of the mid-tones. In interactive contrast enhancement, the most commonly used transformations are the gamma transformation and the sigmoid transformation. The gamma transformation either lightens the image by raising shadow contrast and lowering highlight contrast or darkens the image by lowering shadow contrast and raising highlight contrast. The sigmoid transformation raises mid-tone contrast by darkening shadows and lightening highlights while lowering their contrast. A flexible contrast enhancement transformation should encompass the full range of gamma and sigmoid transformations. To maintain the global consistency of the image, it should preserve the endpoints of the range of tones displayed by the image. To allow the transformation to be appropriately situated in the dynamic range, it should only alter the relevant tones while leaving the rest unaffected.

In order to satisfy these requirements, we use our histogram warping transformation, $T(x)$, specified by five control points, (a_k, b_k, d_k). The five control points contain only five independent parameters: the low tone p_l, the high tone p_h, the input mid-tone p_a, the output mid-tone p_b, and the mid-tone contrast adjustment p_d. The five points are: $(a_{\min}, a_{\min}, 1)$, $(p_l, p_l, 1)$, (p_a, p_b, p_d), $(p_h, p_h, 1)$, $(a_{\max}, a_{\max}, 1)$. We require $a_{\min} \leq p_l < p_a < p_h \leq a_{\max}$ and $a_{\min} \leq p_l < p_b < p_h \leq a_{\max}$. The user can simultaneously and independently control the tone shift and contrast adjustment of the mid-tones, $T(p_a) = p_b$ and $T'(p_a) = p_d$, while constraining the effect on the low tones and the high tones, $T(p_l) = p_l$, $T(p_h) = p_h$, and $T'(p_l) = T'(p_h) = 1$. The transformation preserves the tones below the low tone and the tones above the high tone, so that $T(x) = x$ and $T'(x) = 1$ when $a_{\min} \leq x \leq p_l$ and $p_h \leq x \leq a_{\max}$. When $p_d > 1$, if $p_a = p_b \approx p_l$ or $p_a = p_b \approx p_h$ then the histogram warping transformation (Figure 5(a) and (c)) resembles a gamma transformation. When $p_a = p_b \approx (p_l + p_h)/2$ then the histogram warping transformation (Figure 5(b)) resembles a sigmoid transformation.

We settled on five parameters because this is the minimum that provides the required flexibility. To achieve analogous effects in the context of global automated contrast enhancement, Shyu and Leou require nine parameters [SL98]. Clearly, we could introduce more; the histogram warping method supports an arbitrary number of control points. However, for these experiments we favour simplicity and comprehensibility over complete flexibility.

We implemented contrast brushes as a stand-alone tool. The final version is shown in Figure 6 along with explanation of the various features.

7. User study

The evaluation paradigm during development was quick and informal; such evaluation is an essential ingredient of successful design [PRS02]. The three techniques used were the usual methods: observing users, asking users, and asking experts. The results of these evaluations were formative and qualitative, allowing us to refine the system to that shown in Figure 6. We informally found this implementation of contrast brushes to be an effective user interface for applying powerful contrast enhancing effects.

To evaluate formally the usability of our present system and motivate future improvements, we conducted a preliminary user study. We compared the performance of contrast brushes to the contrast enhancement tools in Adobe Photoshop, which supports a far richer and complicated set of features, including controls for adjustment layers, histogram levels, transformation curves, local dodging and burning, as well as global brightness and contrast.

Our study had six participants, all of whom were already familiar with basic image editing using Adobe Photoshop

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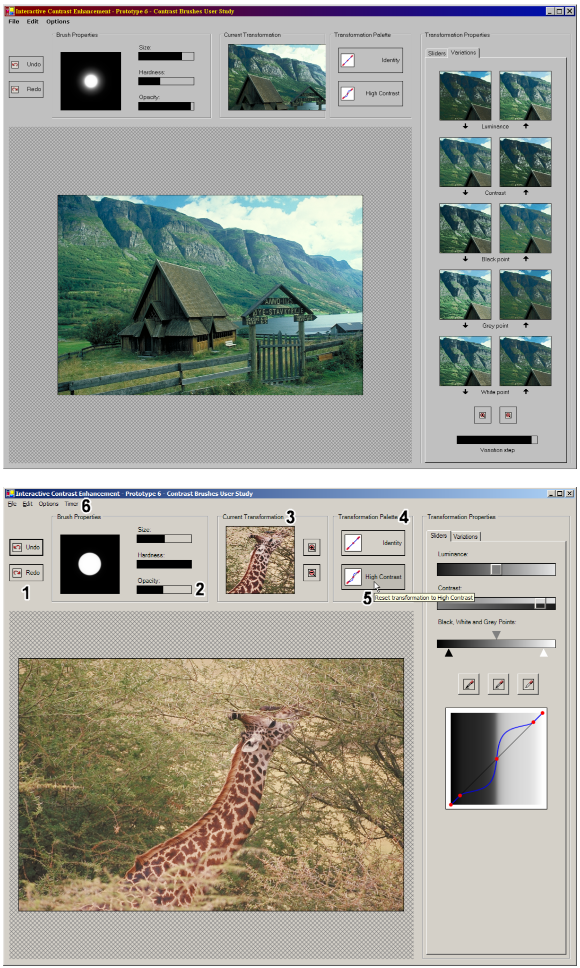

Figure 6: *Screen shots of the contrast brushes application. At the top, the design gallery type interface; at bottom: the sliders and graph interface. Five parameters can be adjusted: the black, grey, and white points are* p_l*,* p_a*, and* p_h*. The luminance slider adjusts how the output,* $p_b = T(p_a)$ *relates to the input,* p_a*. The contrast slider adjusts the slope,* $p_d = T'(p_a)$*, at* $x = p_a$*. In the design gallery version, there is a preview of the transformation after each of the ten possible changes to the transformation. The numbers in the lower screen shot indicate other features: (1) undo and redo are essential for experimental image manipulation; (2) the brush follows the same pattern as the painting brushes in Photoshop, allowing adjustment of size, hardness (allowing feathered brushes), and opacity; (3) a preview of the current transformation is shown applied to a sample of the image; (4) two default settings are available as buttons for fast resetting of the parameters; (5) all controls have tool tips to help users in the user study; and (6) a timer was implemented to automate parts of the user study, recording total editing time and the duration of every brushstroke.*

but not contrast brushes. The participants were asked to enhance the appeal of six different greyscale images, with each tool, as they saw fit. To provide context for the task, they were asked to imagine that they were putting together a travel brochure advertising the destinations depicted by the images. The scripted experimental procedure began with a brief introduction explaining the experiment, a demonstration of contrast enhancement using contrast brushes and Adobe Photoshop, and a familiarisation task to allow the participants to become comfortable with both systems. In the experiment, each participant enhanced the six images in randomised order, once using contrast brushes and again using Adobe Photoshop. Counterbalancing was applied to reduce the influence of learning effects, so half the participants used contrast brushes first while the other half used Adobe Photoshop first. Each participant was given a maximum of ten minutes to complete the task for each image for each tool.

After finishing all the experimental tasks, the participants were asked to rate their experience of working with each system using the System Usability Scale [Bro96]. This standard questionnaire is designed to measure the subjective usability of systems on a reliable Likert scale, where each question carries a similar psychological weighting. According to the System Usability Scale, every participant rated contrast brushes to be at least as usable as Adobe Photoshop. Out of a maximum best score of 100, the median score of contrast brushes was 75.0 while the median score of Adobe Photoshop was 57.5. The scores for contrast brushes exhibited slightly less variability. As measured by the Gini mean difference, the expected absolute difference between a pair of scores for contrast brushes was 9.5 and for Adobe Photoshop was 12.7. The participants were also asked to compare contrast brushes and Adobe Photoshop on several criteria. Excluding participants who expressed no clear preference, most participants felt that contrast brushes were more effective, meaning the same contrast enhancing effect could be achieved in less time and the same amount of time spent enhancing contrast could achieve a more useful effect. Most participants also found that contrast brushes were easier to learn and easier to use. Participants were divided over which system was more flexible and more enjoyable to work with.

Finally, semi-structured interviews were recorded with each participant to elicit their opinions of contrast brushes. All participants agreed that they would use contrast brushes if these tools were fully integrated into Adobe Photoshop. Participants praised contrast brushes for the ease and speed of being able to directly "brush the contrast onto the picture" and "to see exactly what you would be painting" through previews, enabling fast experimentation with new ideas for enhancing the picture. However, participants criticised contrast brushes for making it "very hard to rework changes you've made to the image" as well as its lack of standard Adobe Photoshop features, in particular a history palette and a histogram display. Participants were more accustomed to working with a visualisation of the image histogram rather

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than the curve of the image transformation. To tune the transformation, they preferred the more familiar sliders interface to the unfamiliar variations interface because the sliders were quicker and more precise to use. They suggested several possible improvements to the contrast brushes system, including an erase brush to selectively remove contrast enhancement from the picture, a brush palette to store and reuse previously configured transformations, an interface to edit previously made brush strokes, and additional support for a graphics tablet. Extending contrast brushes to handle video is a challenge for future research. From demonstrating contrast brushes to several film post-production companies, we have learnt that current tools offer much less scope for locally applying contrast enhancement to video.

8. Summary

Contrast brushes are an interactive method for directly brushing contrast adjustments onto an image. They are a carefully constrained application of histogram warping, which provides guarantees about the quality of the adjustment (no halo or contouring artifacts) with straightforward controls (five parameters for the contrast adjustment and three parameters for the brush). A user study demonstrates that contrast brushes are more effective than the state-of-the-art contrast adjustment methods.

Subsidiary material and contact details

Send correspondence to Mark Grundland: Mark@Eyemaginary.com A colour version of this paper along with supplementary materials, including videos of the contrast brush tool in action, can be accessed at: http://www.Eyemaginary.com/Portfolio/Publications.html

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