2D image lighting and shading

SIGGRAPH ASIA 2013

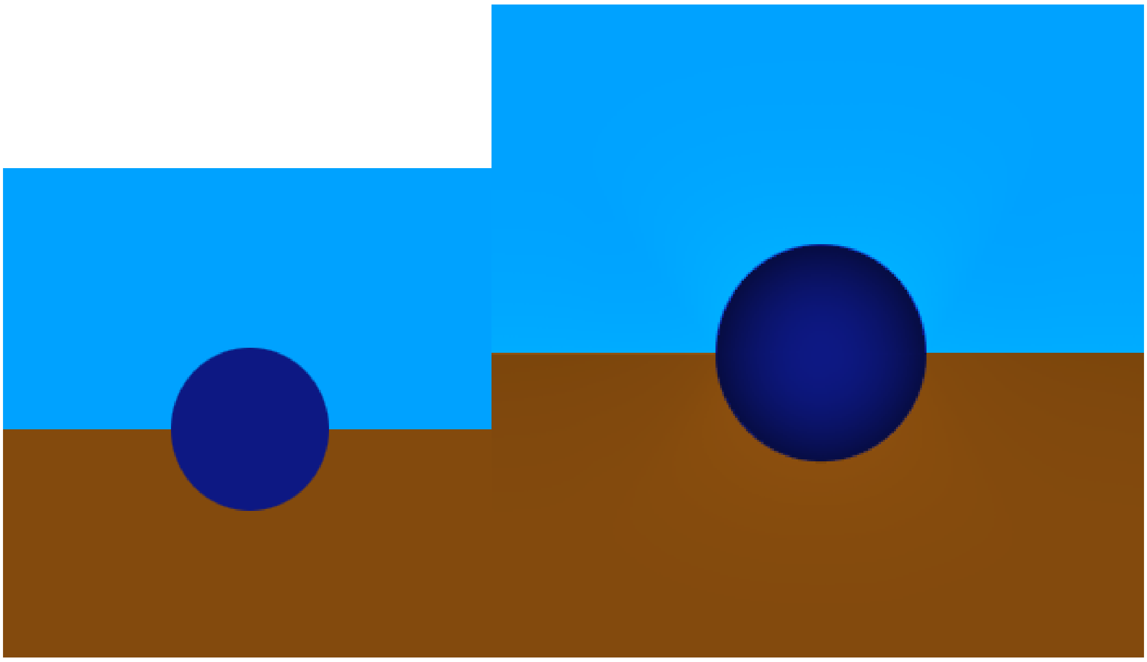
Idea: 3D shading in 2D images using surfaces.

Motivation: The tricky problem of shading images has been extensively studied in computer graphics. Most shading algorithms rely on information such as 3D models, distance to camera and surface normal vectors. Traditional artists, however, have for centuries been able to shade the objects in the drawings and paintings in a plausible and expressive manner, without this information. Inspired by 2D drawing techniques and perceptual psychology, we propose a framework that adds light and shade to 2D images, without any prior information.

Contributions:

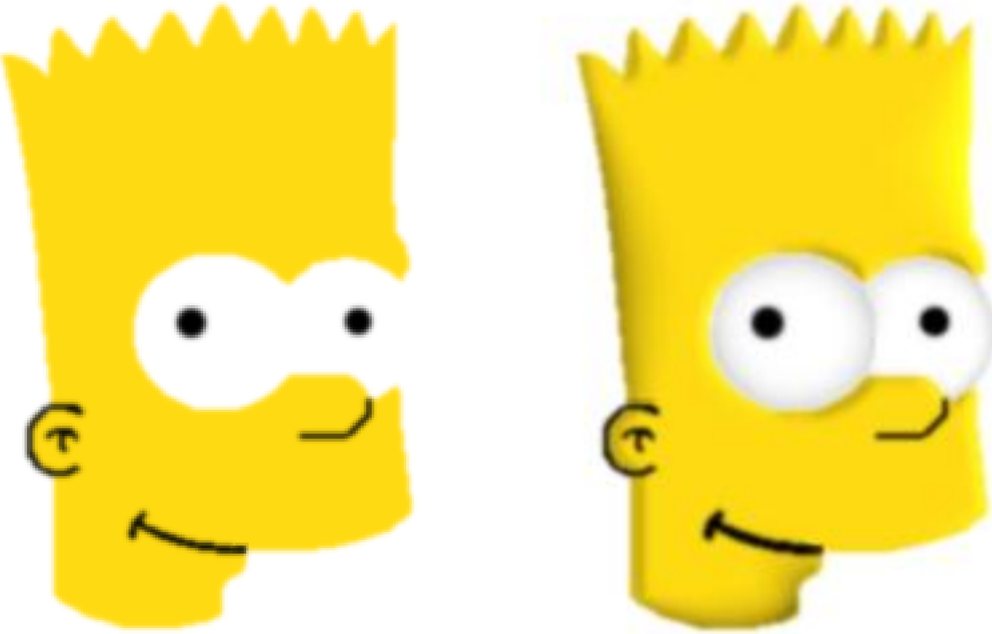
1. A novel 2D shading technique using continuous surfaces that does not require 3D information.
2. A framework for artistic image shading and lighting that, compared with related tools:
    - has more degrees of freedom,
    - is more adaptive to expressive imaging, and
    - is proven qualitatively to be preferable by the artists we interviewed.

Initial results using surfaces



2D circle to 3D sphere

Shaded boundary on artistic filtered image.



Shaded boundary from artistic drawing.

Added light (from top left).

Related work

Shading and perception in imaging

Surface Flows for image-based shading design (SIGGRAPH 2012): Image deformation operators from normal or depth maps for image shading. The advantage over diffusion-related approaches is that it does not require as much artistic input (only normal or depth maps). However, my thinking is that we can achieve similar results (perceptually) by shading 'some pixels' without using normal or depth maps. That is, edge maps or boundary edge maps might suffice.

CrossShade: shading concept sketches using cross-section curves (SIGGRAPH 2012): estimate normal map from 2D cross-section curves. Use the normal vectors for shading.

Visual equivalence: towards a new standard for image fidelity (SIGGRAPH 2007): A perceptual model of the perceptual equivalence between blurred and warped illumination maps, and the reference solution is proposed. A similar study could be done, comparing the visual equivalence between our method and related methods (e.g. surface flows).

Images-based material editing (SIGGRAPH 2006): By using the illumination channel as depth buffer, materials can be replaced from single images. While this works for material editing, adding for example reflective and refractive properties to the object, this would probably not work for surface flows, since it requires accurate depth maps.

Textureshop: texture synthesis as a photograph editing tool (SIGGRAPH 2004): normal maps and texture synthesis are combined, creating realistically-looking textures onto objects in images.

Image diffusion

Diffusion Curves: a vector representation for smooth-shaded images (SIGGRAPH 2008): A vector representation for smooth-shaded images. Colours are associated on both sides of each vector. Laplacian diffusion colours the image.

Real-time gradient domain painting (SIGGRAPH 2008): Similar to Diffusion Curves. It handles non-zero Laplacian internal conditions and Neumann domain boundaries, rather than internal Dirichlet boundaries.

Estimating colour and texture parameters for vector graphics (EUROGRAPHICS 2011): fix colour and texture problems in diffusion curves.

Texture design and draping in 2D images (EGSR 2009): extend Diffusion Curves to support texture editing via normal maps.

Diffusion constraints for vector graphics (NPAR 2010): Adds constrains to Diffusion Curves: diffusion barriers that block diffusion, control over diffusion anisotropy and orientation, and control over diffusion strength. All these must be specified by the artist.

Rendering surface details with diffusion curves (SIGGRAPH Asia 2009): render diffused textures onto 3D objects.

A GPU Laplacian solver for diffusion curves and Poisson image editing (SIGGRAPH Asia 2009): GPU implementation of Diffusion Curves.

Freeform vector graphics with controlled thin-plate splines (SIGGRAPH Asia 2011): Higher order diffusion based on thin-plate splines which provide smoothness everywhere except at user-specified tears and creases.

Problems with diffusion: surfaces are well-behaved, but difficult to control (since the solution simply converges to the limit surface, which might not be what we want). Also, we do not necessarily want to diffuse the whole image or whole image regions. Simply changing the pixels close to what we want to shade should be enough.

Other

Another related field is sketching and modelling, more specifically, modelling 3D surfaces from curves. One recent example:

A linear variational system for modelling from curves (EG Symposium on Geometry Processing 2012): A linear system for modelling 3D surfaces from curves, using a constrained high-order Laplacian editing framework.

Perception of shape

These are the main papers and books on the perception of shape that everyone seems to be citing.

Specular reflections and the perception of shape (Journal of Vision 2004): For reflective and specular surfaces, the local shading orientation signals are organised into smoothly-varying distortion patters. The dependency of specular distortions on the second derivative of the surfaces leads to distinctive orientation fields, encoding 3D shape information.

Lightness perception and lightness illusions (The New Cognitive Neurosciences 2000): inspired by optical illusions, it is hypothesised that at every point in an image, there exists an apparent atmospheric transfer function mapping reflectance into luminance. This map is unknown.

Effects of different texture cues on curved surfaces viewed stereoscopically (Vision Research 1993): Human shape-from-texture proceeds under the assumption that textures are statistically isotropic.

Perception as Bayesian inference (Knill and Richards 1996):

Shape from texture: Ideal observers and human psychophysics: Three textural cues to shape: compression, density and perspective.

Experiencing and perceiving visual surfaces: When faced with more than one surface interpretation of an image, the visual system assumes it is viewing the scene from a generic, not an accidental, vantage point.

The perception of shading and reflectance: can be described as a decomposition of the image by reflectance (r) and shading (s) images: I=r*s. The reflectance image is formed by both shading and reflectance edges. s=dot(N,L).

Does the brain know the physics of specular reflection? (Nature 1990): The human visual analysis seems to employ a physical model of the interaction of light with curved surfaces, a model firmly based on ray optics and differential geometry.

Shape from shadows (Journal of Experimental Psychology 1989): The visual system verifies only the luminance along the border of a region to determine whether it is a shadow. The shadow shape is used in three ways when retrieving 3D object shape: The shadow contour is matched against familiar prototypes. Shadows contribute to the analysis of surface curvature in signalling convexity along the terminator and extremal contours and concavity within closed shadow regions. Some shadow borders provide information about surface relief and object shape.

Three gradients and the perception of flat and curved surfaces (Journal of Experimental Psychology 1984): There are three main gradients (sources of information that grade or change) that affect the perception of flat and curved surfaces: perspective, compression, and density. Perspective is important and compression is not important for perception for flat surfaces. Similarly, perspective is not important and compression is important for curved surfaces. Density gradients are of secondary importance which reinforce perspective gradients.

Perception of surface curvature and direction of illumination from patterns of shading (Journal of Experimental Psychology 1983): The shininess of a surface enhances the perception of curvature, but has no effect on perceived direction of illumination. Shading is generally less effective than texture for depicting surfaces in 3D.

Apparent spatial arrangement and perceived lightness (Journal of Experimental Psychology 1954, later refined in Science 1977): When a surface of a given illumination is perceived as being perpendicular to the direction of illumination, it appears less bright than when the same surface, with the same illumination, seems parallel to the direction of illumination.

Surface colour perception (Beck 1972): Study on colour constancy in relation with objects and shapes.

Shape and shading in traditional art

Optics, painting, and photography (Pirenne 1970): study on how the flat canvas affects the perception of dimensionality, in particular the tricky problem of perspective. The main message is: 'Ordinary pictures viewed binocularly in the usual manner do not give a genuine three-dimensional representation of their subject matter. In spite of the fact that it may give a strong *suggestion* of depth, the representation given by ordinary pictures is of a *sui generis* nature, and depends on the spectator's subsidiary awareness of the characteristics of the picture surface. This at once shows that ordinary photographs do not, any more than paintings, give a perfect imitation of the scene they represent.'

The art of responsive drawing (Goldstein 1973)

Value: light, local-tone, and mood: Light can be added and edited to convey the impression of volume and space. Drawings in which light is the dominant graphic idea, infer a view of our world as existing in darkness; darkness is the norm, light is the transitory, revealing exception. The elements of light:

1. The lightest value of an illuminated form, or *highlight.*
2. The next lightest value, or *light-tone.*
3. The third lightest value, often found on surfaces parallel to the direction of the light rays, or *halftone.*
4. The darkest value, or *base-tone.*
5. The usually weak light cast upon the side of a form turned away from the light source, *reflected light* results from deflected light rays from the light source.
6. The dark tones resulting from the blocking of light rays by solid bodies, or *cast shadows.*

On specular highlights: 'Direct highlights, on rounded forms, are relatively unimportant because they describe only a small area of a form, contributing a little. We understand a subject's volume mainly through its major structural character.'

Additionally, value can help the artist to convey his expressive responses to a subject.

Drawing light & shade: understanding chiaroscuro (Civardi 2006)

Tone and tonal values: density and strength (i.e. 'blackness') dictates the shade of the surface at any given point. Cross-hatching is a simple technique for showing the various degrees of tonal intensity (i.e. more crosses equal darker shade). Cross-hatching can 'follow the shape' using strokes that follow the direction of the longest sides or 'contrast of the shape' using short strokes that go against the longest sides. Note that in chiaroscuro, it is usual to limit the range of tonal graduations to not more than eight or nine. The tonal changes should appear decisive but gradual, without sharp linear contours.

Suitable tools for chiaroscuro: HB graphite, 6B graphite, water-soluble graphite, pen and ink, willow charcoal, and compressed charcoal.

Light emphasises the relief of whatever it is illuminating and gives the feeling of volume, space and atmosphere. Light in front of the subject flattens the relief and suggests a flat, rather than solid shape. Side lighting, on the other hand, highlights the volume, dividing the overall shape into two halves.

Some historical uses of chiaroscuro: expressive and dramatic (Caravaggio), profound existential experience (Rembrandt), glance at intimate, suspended life (Vermeer), brightness of the sun in nature and a luminous atmosphere (Monet).

Problem description

Idea: 3D shading in 2D images using surfaces.

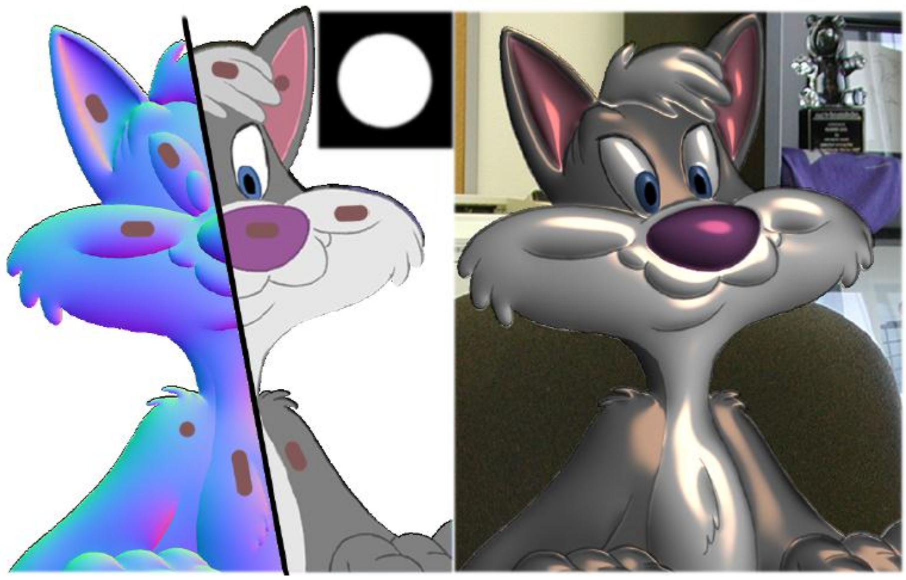
First, the hypotheses are discussed.

A novel 2D shading technique using surfaces that does not require 3D information.

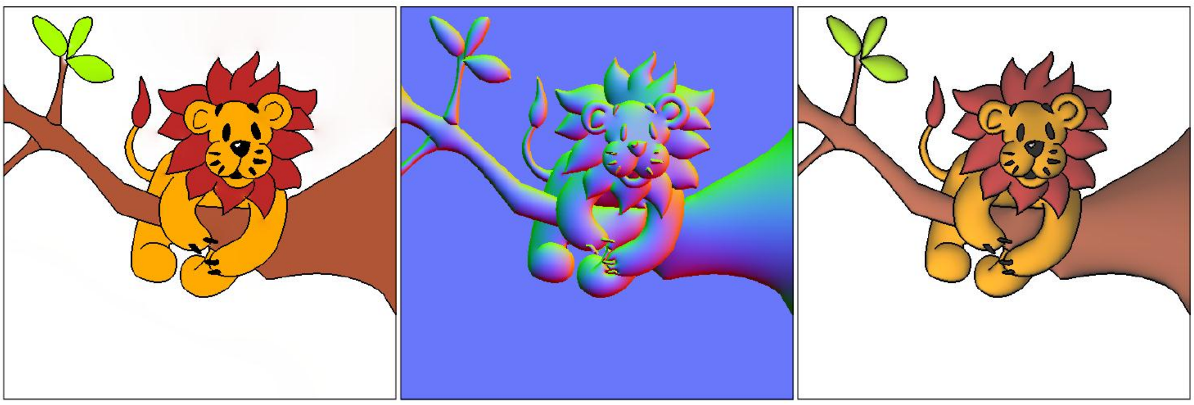
We will have to prove, via an experiment, that our 2D shading technique creates similar results to Surface Flows, without normal or depth maps. Thus, the aim is to show that normal or depth maps are not needed for shading 2D images. It is however needed when distorting texture, which according the psychology literature have the strongest effect of 3D shape. Do the experiments on simple cartoon-like images, since this will remove unwanted variables in the experiment (like noise, already shaded pixels etc.). Also compare with Photoshop’s bevel and emboss contour.

Input for our method: edges (and maybe scribbles)

Input for Surface Flows: normal or depth map, anchor points (where the deformation is required to have no effect), brush strokes.



Result from surface flow.



Result from diffusion constraints.

An artistic toolset for image shading that, compared with related tools:

has more degrees of freedom

Compared to Diffusion Curves, we have obviously more degrees of freedom. Here, the artist simply provides a set of edges and the associated colours, and the image is diffused. Optionally, the diffusion can be constrained (NPAR 2010), but it is still a diffusion process. Explicit shading is rather difficult.

Surface Flows is quite decent for artistic control. Though, it seems like the strokes only dictate specular highlights. The actual shading is driven by depth or normal vectors. From art and perception, we know that specular highlights are unimportant for lighting and shading effects.

In our system, it should be trivial to change the shape or gradient of the shading, thus directly adding any of the six elements of light from Goldstein [1973]. Additionally, the artist can add lights or direction of light that automatically set the values of the surfaces (i.e. whether they are positive or negative). Though, we might want to rephrase this, since Photoshop has more degrees of freedom.

is more adaptive to expressive imaging

Diffusion Curves is limited to expressive imaging, since the images are automatically computed from the user input. Hence, the artist needs to be aware of how the diffusion process colour the image for full control of the image editing.

While the artist in Surface Flows can easily edit specular highlights and texture according the object's surface, and drag its shading, it is not trivial to edit the actual shading of the object. From art, we know that this is highly important in order to express any desired mood. This would only be possible by editing the normal or depth maps directly.

We already have control of the value of the shading, that is, the shape of the continuous surfaces. We will also need to provide control over how the surfaces are drawn onto the image. Abstracting the materials used for drawing lighting and shade would be necessary to provide the tools for expressive imaging. Using the six tools outlined by Civardi [2006] should suffice (that is: HB and 6B graphite, water-soluble graphite, pen and ink, willow charcoal and compressed charcoal). The surfaces should dictate the strength, or density, of the strokes.

is proven qualitatively to be preferable by the artists we interviewed

(is not sure whether to use the word 'prove')

Diffusion Curves starts off by an empty canvas. The artist will need to provide the edges of the gradients in the image. Surface Flows starts off with a blurry, cloudy image. The artist needs to provide anchor points and various strokes.

Our method inputs a flat 2D cartoon image (like the Bart image), or a photograph. The photograph should either be NPR filtered, or separated into intrinsic images. Shading an already shaded image does not make that much sense. Edge detection (which is fairly trivial for cartoon images) or edges from user strokes is necessary. This will produce 'something'. Additionally, lights or direction of light, type of strokes, direction of strokes can be added or edited. The surfaces can also be edited in a separate window.

I think we have to do some interviews with artists that are aware of this kind of art to make our argument stronger. Not sure whether we have to simply do an informal interview or do an actual user study. Though, a professional artist would prefer Photoshop. However, we could show that our system produces similar results to Photoshop, only faster.

The framework

Input

Since the competition already uses quite a lot of input, simply letting the user provide edges would be a valid argument. If the input is a cartoon image, the edges can be extracted from simple edge detection. We should produce *something* out from this. Then, the result can be interactively refined by the artist, by adding type and direction of strokes, editing the NUBRS, and adding lights.

Suggested test pool: 20 cartoon images, similar to Bart image. 10 photographs of faces and objects. If possible, try to separate shading and illumination using some kind of intrinsic image technique (if I find code for it). Filter the photos with various NPR filters.

The main components

First, fit the edges to cubic B-splines. Use the same approach as the previous project. Maybe, instead of inserting a triple knot at high-curvature points, just sample that area with more pixels. Since we are probably vectorising the image, the continuous curves will replace the original discrete curves. We therefore do not need to think that much about intersecting the high-curvature control points. Thus, if the spline only follows the original curve close enough, we are happy.

Shape of the surfaces

In the Cornsweet project, we wanted the NURBS to extend as far out as possible. This is not required here I think. We only need to ensure that surfaces do not overlap. Doing a level set approach to place the control points at a given distance from the curve should produce what we want. At high-curvature areas, initial tests with Jiri shows that we can still create these triangular patches. Instead of sampling the parameter space of the NURBS control points we can create similar surfaces (or the same at quadratic patches) with subdivision surfaces. The problem with extraordinary vertices where the continuity is C_1 will not make any visible artefacts, from our very simple initial results. The art literature does not tell us any ideal extent and value of the shading. Stronger values and farther extents will create the illusion of stronger light. We will set the extent and z-values of the surfaces to some reasonable constant value. Then the artist can change this, either by a single parameter, or by dragging the surfaces in the x-y plane.

Drawing the surfaces

Draw the surfaces onto the images in a similar way to the last project, only faster, using GPU texture mapping. Work exclusively in the luminance space (which space exactly? Lab? Yxy?).

We do not need to think about inpainting close to the edges since we are vectorising the images.

We do need antialiasing. Use the same blurring approach as Diffusion Curves.

Optional: brushes. Paint brush strokes in the given direction (by the artist). The surfaces dictates the strength and density. For each brush, make a continuous map from the z coordinate of a surface to strength and density. TODO: FIGURE OUT HOW TO DO THIS. CAST SHADOWS? PERSPECTIVE?

Timeline

Here's a timeline:

4-8 Feb:

- Build the main framework in C++, basically reimplementing the previous paper.
- Get results from other papers.

11-15 Feb:

- Add user interface for changing the surfaces.
- Discretise the surfaces using GPU texture mapping.
- Add light or direction of light and dictate the surfaces by this.

18-21 Feb:

- Add antialiasing and blurring ?
- Specular highlights.
- Shadows.

25 Feb - 1 March:

- Add brushes.

4 – 8 March:

- Add brushes.
- Smooth transition between dark and light shading.

11 – 14 March: SIGGRAPH 2013 rebuttal.