Mesoscopic Phenomena in Rendering: Moire Effects

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I propose to develop photorealistic renderers capable of accurately and efficiently computing multiplicative interference effects, such as those that produce moire patterns. This work would be immediately applicable to architectural and cloth rendering, where such effects are commonly employed. It would also advance our knowledge about visual mesoscopic phenomena, i.e. large scale structures arising from small scale structures.

Background

Since the introduction of aliasing literature to computer graphics[Crow 1977, Mitchell 1990], moire patterns have been associated with aliasing artifacts. However, moire patterns also occur independently of sampling and reconstruction processes. The term moire goes back to the mid 17th century and derives from the fabric mohair, which was specially processed to produce so called "watered" effects. In recent years, notable architectural firms such as Steven Holl and Herzog & deMeuron have used moire effects in their facades. Just looking around, everyday objects like rotary fans naturally produce moire effects. They are a ubiquitous part of the man-made world, regardless of whether we choose to render them.

Theory

We can see moire effects as one instance of a more general phenomenon: multiplicative interference. Multiplicative interference arises in computer graphics through occlusion. Given a grating, either light is let through, equivalent to a scaling factor of 1, or light is occluded, equivalent to a scaling factor of 0. When light passes through multiple gratings, a composite function results as the product of successively encountered gratings. In the simple case of sinusoidal occlusion functions, we see that this interference can create lower frequencies in the signal:

$$2\sin(80x)\sin(60x) = \cos(80x - 60x) - \cos(80x + 60x) = \cos(20x) - \cos(140x)$$

Therefore, if we independently pre-filter the two gratings for a Nyquist limit of 30, we will just get a constant function, even though we ought to have captured the frequency of 20. If we instead represent the gratings by their frequencies (60 and 80) and pre-filter after composition, we will retain the frequency of 20 in the final image.

Generalizing this idea, multiplication of two occlusion functions in the spatial domain is sent, under the Fourier transform, to convolution in the frequency domain. Since periodic functions have very compact frequency domain representations, we get compact representations of occlusion functions for gratings and an effective means of composing them. Furthermore, it is a simple and direct matter to pre-filter a signal already in the frequency domain.

Proposed Work

I propose both to develop immediate solutions for the simpler instances of multiplicative interference effects and to investigate the plausibility of approximation.

Most immediately, I plan to extend a photo-realistic raytracer such as PBRT[2004] with per-ray occlusion functions and frequency-domain grating textures. In order to do this, I will investigate efficient function bases for representing and composing occlusion functions. In all likelihood, variants of the Fourier basis will work better than the standard Fourier basis. In particular, chirp basis vectors better capture the frequency-space effect of projective transformations on the grating patterns. Further extensions will investigate the possibility of spatially varying patterns, which will require wavelet and/or chirplet bases. Pursuing this line of thought to its logical end, I will consider the problem of handling 3 dimensional relief, such as gates made of woven strips of metal.

Secondly, how necessary is multiplicative interference to generating visually plausible pictures? If you consider the presented picture of a watered silk dress you will notice the obvious moire patterns on the skirt. What about the folded shoulder fabric? It is much harder to tell whether or not multiplicative interference is at work. However, with an accurate renderer capable of generating ground truth images, we can answer this question. I suspect that multiplicative interference plays a significant, non-obvious role in visual phenomena beyond moire patterns.

Related Work

To my knowledge, no one has done any work on rendering moire patterns or multiplicative interference effects in a 3d scene. The closest reference in the graphics literature is Hersch and Chosson[2004], who presented work on designing band moire images in 2d. This work focused on a restricted set of patterns and stressed applications to security watermarks. Of a similar philosophical position to the proposed work is Han et al.'s "Frequency Domain Normal Map Filtering"[2007]. There, normal maps are downsampled to maps of BRDFs (analogously to the occlusion functions described here) in order to preserve the distribution of reflection directions.

Broader Impact

The techniques developed in this research will be immediately applicable to more realistic architectural and cloth renderings. They will significantly improve the quality of perforated cloth rendering in wedding dresses and other layered fabrics. Similarly, they will significantly improve the accuracy of architectural renderings of buildings using gratings or other small periodic elements, allowing both for the detection of unwanted moires or intentional design thereof.

For computer graphics this work will help draw attention to mesoscopic phenomena. By understanding how microscopic geometry creates macroscopic effects we will be able to design more efficient and accurate level of detail and pre-filtering schemes.

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