Compressing and Companding High Dynamic Range Images with Subband Architectures

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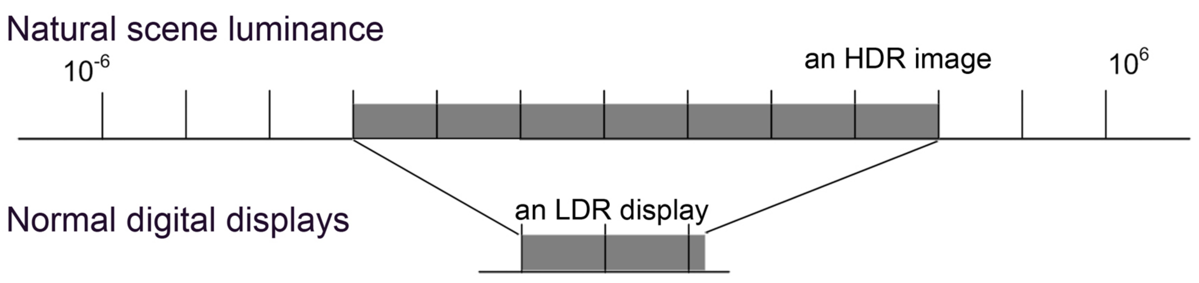
Dynamic Range Problem

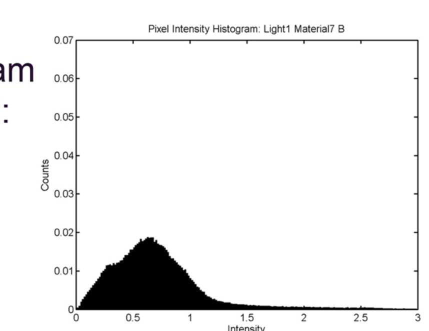
Natural scenes contain huge ranges of luminance, and it has recently become convenient to capture high dynamic range (HDR) images digitally. Unfortunately there is no easy way to display them on a low dynamic range (LDR) display.



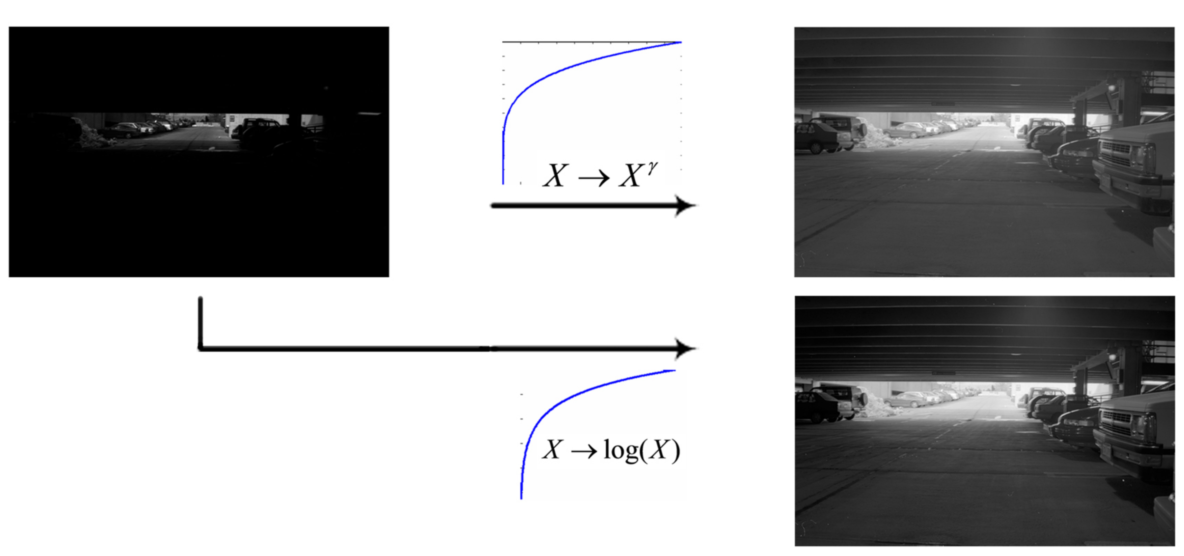
In Our Study of Material Perception

Some materials have high dynamic ranges, for example due to specular highlights and dark crevices

The intensity histogram of the above material:



Easy Things to Do: Sigmoid on Intensities



Problem: details are compromised.

Filtering techniques to preserve details:
- Idea: the local average (low frequency) is correlated with illumination and can be compressed.
- Stockham'72, hormormorphic filtering
- Problems: cusps, or say, *halos*

Robust filtering to reduce halos:
- Outliers are penalized
- Anisotropic diffusion (Perona&Malik'90)
- Bilateral Filtering (Tomasi&Manduchi'98, Durand&Dorsey'02)

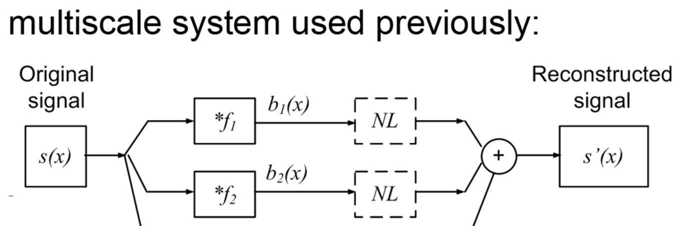
Gradient domain manipulation (Retinex-like):
- Fattal et al.'02
  - -- Big gradients are compressed
  - -- Then solve the 2D Poisson equation

Photographic tone mapping: Reinhard et al.'02, etc.

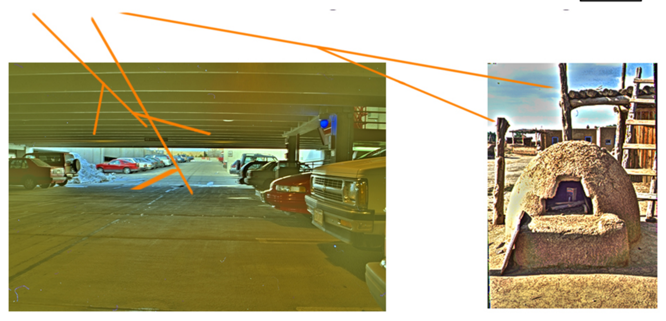
Multiscale Techniques

While widely used for many other image processing tasks, have a reputation of causing halos when used for range compression.
- Pattanaik et al.'98, Jobson et al.'97, Tumblin&Turk'99, Dicarlo& Wandell'01, Lee'01, Vuylsteke&Schoeters'98

an example multiscale system used previously:



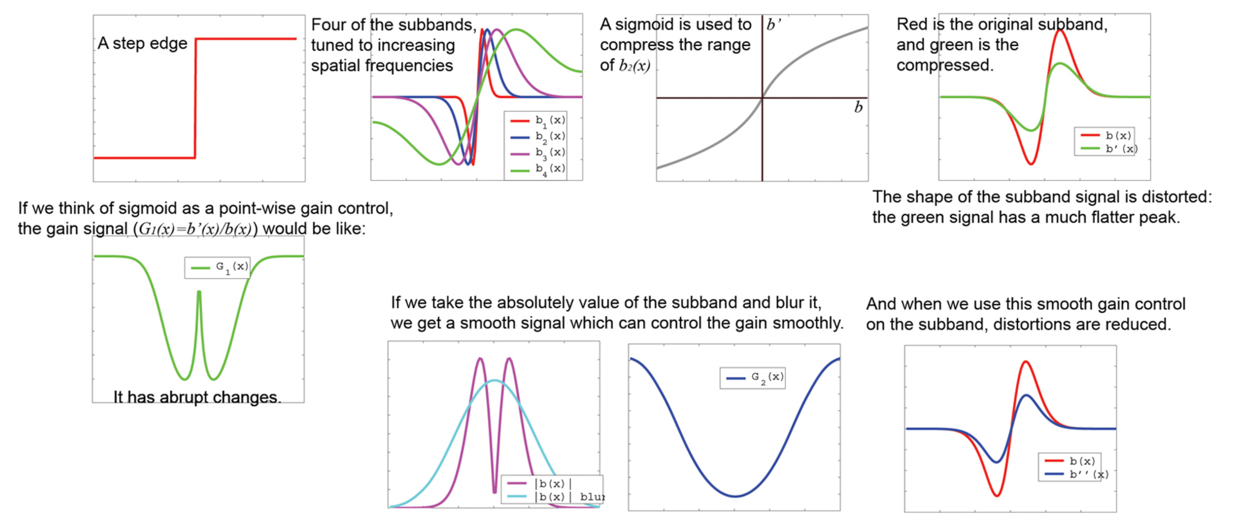
halos along high contrast edges



Here an image is decomposed into a set of subband images tuned for different spatial frequencies. A nonlinearity (NL, usually a sigmoid) is imposed on each subband, and the modified subband images are then summed to give the result:

Nonlinear Distortion

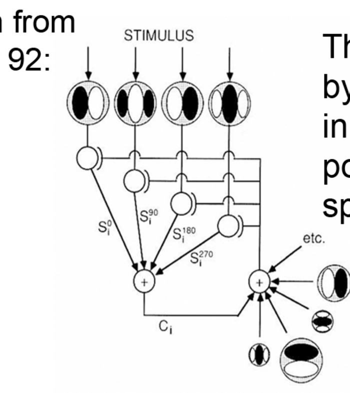
The nonlinearity (NL) causes nonlinear distortion in the subband signals, which we feel is a cause of the halos. We take a 1-D step edge signal as an example.



Gain Control in the Human Visual System

And human vision does use smooth gain control. Here we look at two types of automatic gain control in the human visual system. The first one happens at the retina, where the photoreceptors rapidly adapt to the ambient light level. Another type occurs in V1, where it is known as "contrast gain control" or "contrast normalization" [Heeger 1992].

A graph from Heeger 92:

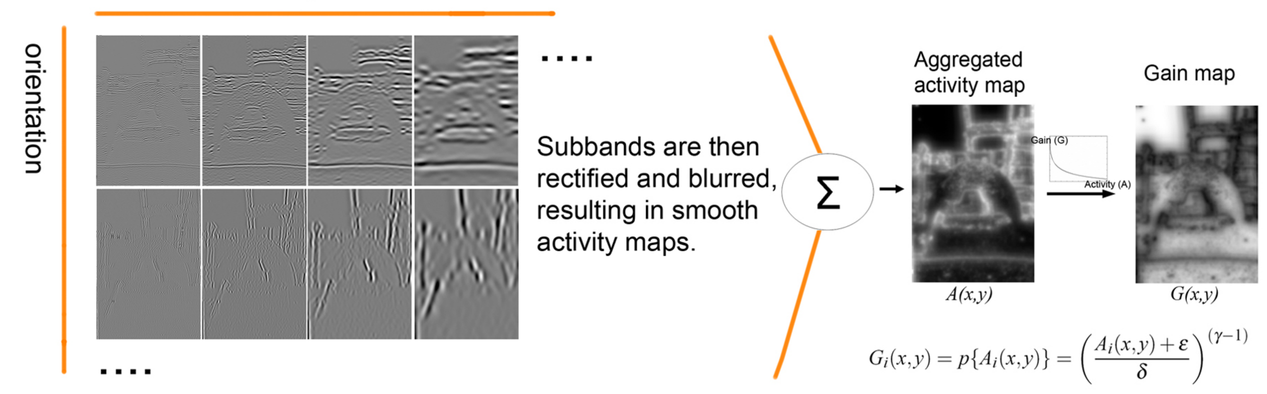


The gain of a given neuron is not only controlled by the activity of itself, but also by many neurons in its neighborhood. Not just from neighboring positions, but also from multiple orientations and spatial scales.

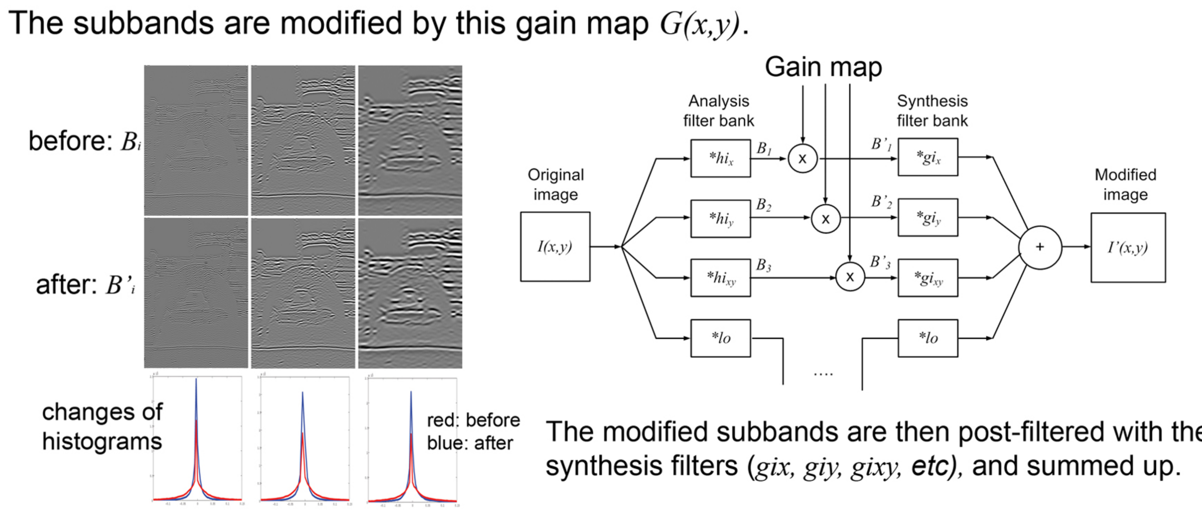
Range Compression

We start by taking the log of the input intensity, which crudely models the retinal gain control. We then decompose the image into subbands with filters tuned for different orientations and spatial frequencies, which is similar to what V1 neurons do.

Subbands:



The subbands are modified by this gain map $G(x,y)$.



The modified subbands are then post-filtered with the synthesis filters (gix, giy, $gixy$, *etc*), and summed up.

Range Compression Results

Companding

12-bit HDR --compress-- 8-bit LDR --expand-- 12-bit HDR

Applications:
Driving HDR display with an LDR laptop
HDR image compression: storing HDR images as JPEG's

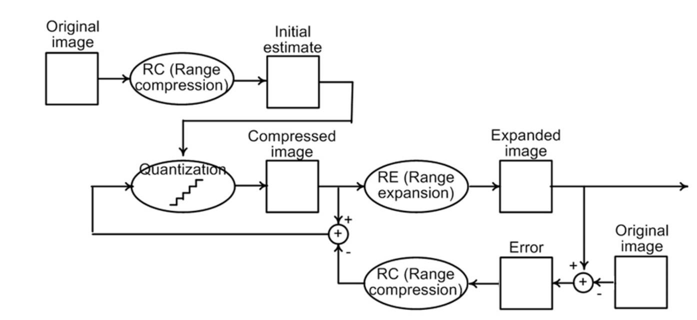
Encoding(compression)/Decoding(expansion) workload:
- -Decoding should be fast, though encoding can be slow
- -Decoding should be standard, though encoding can be versatile

So we first set a decoding (range expansion) technique. Then we iteratively *search* for an LDR image which gives a best approximation of the original HDR image when expanded using this technique.

Range Expansion (RE)

Almost exactly the same as range compression (RC), but divide by the gain instead of multiplying with it.

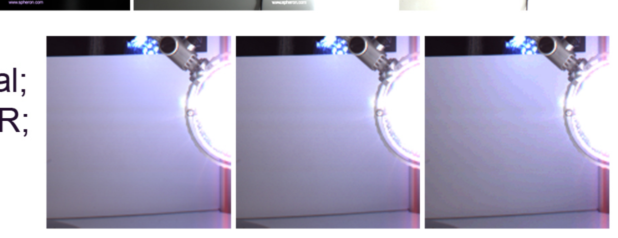
Error Feedback Search



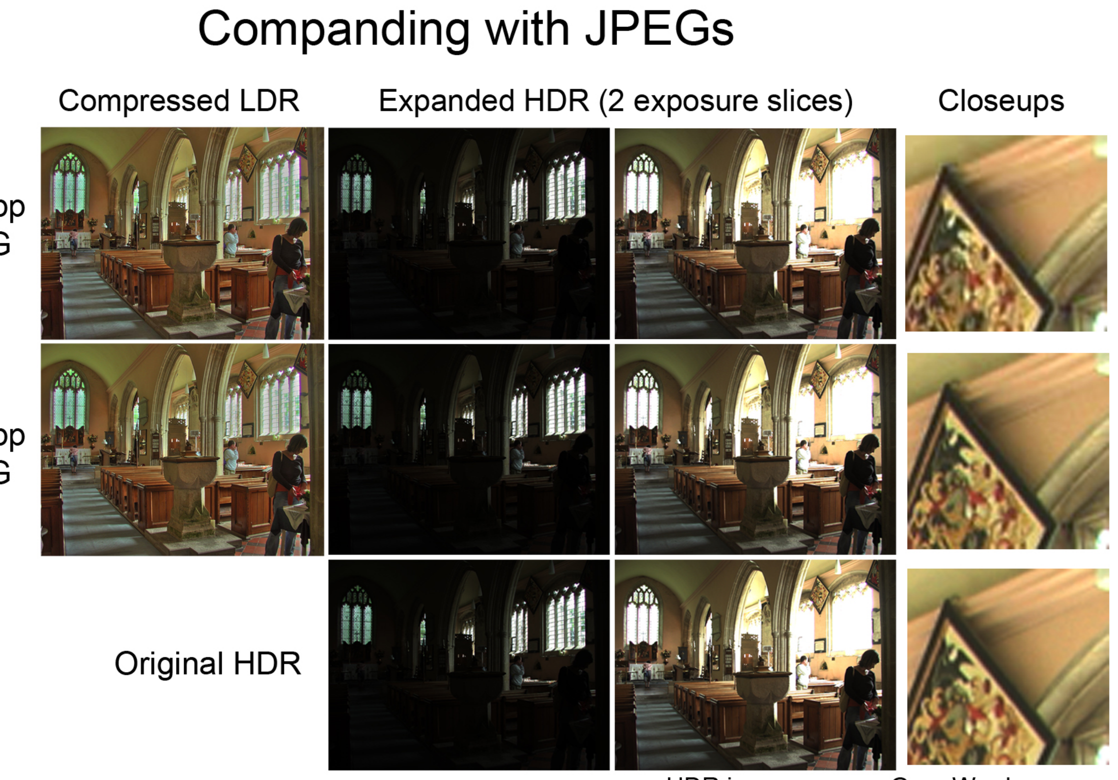
8-bit to 3-bit, then back to 8-bit: (left) original, 8 bit per channel; (mid) range compressed, 3 bit per channel; (right) a 8-bit image expanded from the 3-bit image in the middle.

12-bit to 8-bit, back to 12-bit:
Compressed (8 bit) HDR image expanded from the image on the left

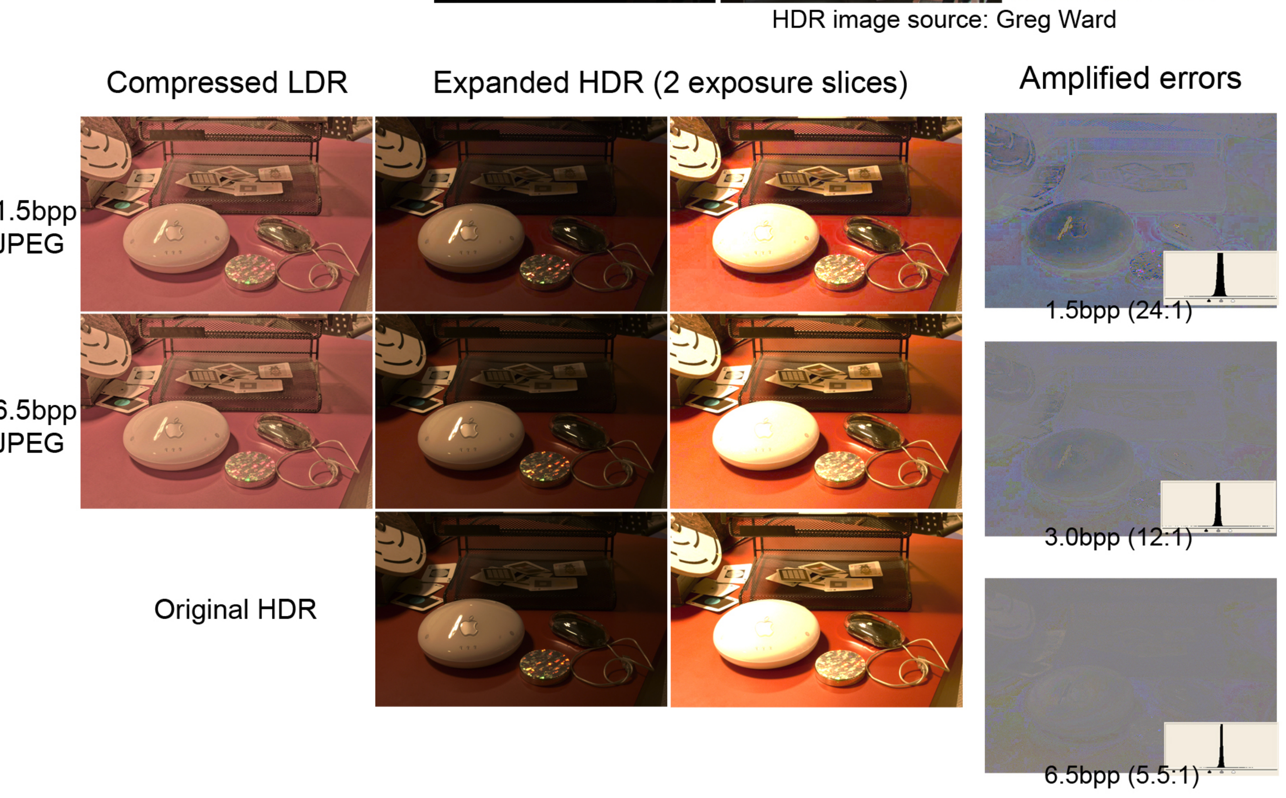
Closeups: (left) the original; (mid) our companded HDR; (right) log quantized.



Companding with JPEGs



HDR image source: Greg Ward



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References:

Heeger D.J. Half-squaring in responses of cat simple cells. Visual Neuroscience. (9), 427–443.
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