MIT EECS 6.815/6.865: Assignment 5:

High-Dynamic-Range Imaging and Tone Mapping

Due Wednesday March 18 at 9pm

1 Summary

- merge N bracketed images into an HDR image
- tone mapping with Gaussian and Bilateral blurs

2 HDR merging

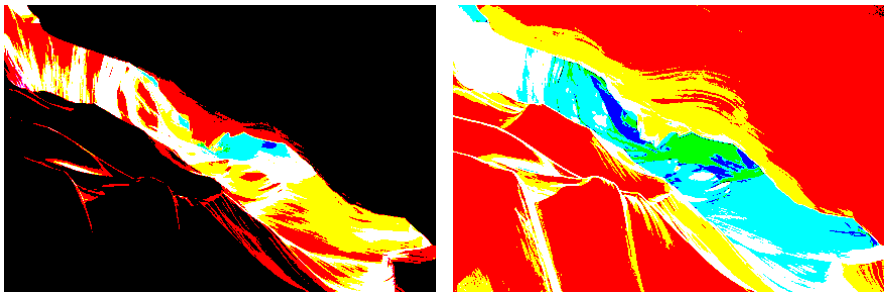
In this assignment, we will only work with images that are linear, static, and where the camera hasn't moved. The image files are provided with gamma 2.2 encoding and we have inserted lines of code in `makeHDR` and `toneMap` to decode and recode, respectively, the images. Keep these lines in your implementations of `makeHDR` and `toneMap`.

Consult the course slides for the overall merging approach. We will first compute weights for each pixel and each channel to eliminate values that are too high and too low. We will then compute the scale factor between the values of two images. Finally, we will merge a sequence of images using a weighted combination of the individual images according to the weights and scale factors.

2.1. **Weights.** Write a function `Image computeWeight( const Image &im, float epsilonMini=0.002, float epsilonMaxi=0.99)` that returns an image with pixel value 1.0 when the corresponding pixel value of `im` is between `epsilonMini` and `epsilonMaxi`, and 0.0 otherwise. Your output weight image should have the same dimensions as your input image `im`. Therefore, this operation should be done on a per pixel and per channel basis. Use `testComputeWeight` in `a5_main.cpp` to help test this function.

2.2. **Factor.** Now that we know which pixels are usable in each picture, we can compute the multiplication factor between a pair of images. Write a function `float computeFactor(const Image &im1, const Image &w1, const Image &im2, const Image &w2)` that takes two images and their weights computed according to the above method, and returns a single scalar corresponding to the median value of `im2/im1` for pixels that are usable in both `im1` and `im2`. Add an epsilon of 10^{-10} to the pixels of im1 to avoid divide by 0 errors. Use `testComputeFactor` in `a5_main.cpp` to help test this function.

2.3. **Merge to HDR** Use the above functions to merge a sequence of images. You can assume that the first one is the darkest one, and that they are given in order of increasing exposure. Write a function `Image makeHDR(const vector<Image> imageList, float epsilonMini=0.002, float epsilonMaxi=0.99)` that takes a sequence of images as input and returns a single HDR image.
Do not forget the special case for the computation of the weight of the darkest and brightest images. You should only threshold in one direction for these cases. If a pixel is not assigned to any of the weight images, then assign it the corresponding value from the first image in the sequance (by doing this you should avoid any divide by 0 errors as well). To test your method, you can write out the output image scaled by different factors. `testMakeHDR` in `a5_main.cpp` does this for the `design` image sequence.



(a) w1 (b) w2

Figure 1: The weights computed from the `ante2` image sequence using the parameters provided in `testComputeFactor`

3 Tone mapping

Now that you have assembled HDR images, you are going to implement tone mapping. Your tone mapper will follow the method studied in class. The function will be called `Image toneMap(const Image &im, float targetBase=100, float detailAmp=3, bool useBila=False, float sigmaRange=0.1)`. It takes as input an HDR image, a target contrast for the base, an amplification factor for the detail, and a Boolean for the use of the bilateral filter vs. Gaussian blur.

As described in lecture slides, our goal is to reduce the contrast from the HDR image (say, 1:10000) to what we can show on a display (say 1:100). Although gamma correction would be the first thing we can think of, this results in washed out images, as shown on the slide "Nave: Gamma compression". The colors are actually okay (they're all there) but the high frequencies are washed out. We therefore want to work in the luminance, and increase the high frequencies, and

we want to work in the log domain, since we are very sensitive to multiplicative contrast (recall lecture 2)!

3.1. First decompose your image into luminance and chrominance using your function from problem set 1 `std::vector<Image> lumiChromi(const Image &im)` that can be found in `basicImageManipulation.cpp`

3.2. Next, compute a log version of the luminance. Add a small constant (e.g. the minimum non-zero value) to the luminance to avoid problems at 0. We recommend you do this by first implementing the `float image_minnonzero(const Image &im)` function, followed by `Image log10Image(const Image &im)`, for which we have written function signatures and comments for you. Then, call `log10Image` with the luminance image as the argument.

Next, we want to extract the detail of the (log) luminance channel. We do this by blurring the log luminance, and subtracting the original. Convince yourself that gives you the details (high frequencies)!

3.3. You are ready to compute the *base (blurry) luminance*. We will implement two versions: Gaussian blur and bilateral filtering [a], which will be chosen based on the value of the input parameter `useBila`. In both cases, we will use a standard deviation for the spatial Gaussian equal to the biggest dimension of the image divided by 50. The parameter `truncateDomain` should be set to the default value of 3.

You are welcome to use your own implementation of filtering methods, but you can also use our versions in `filtering.cpp`.

3.4. Given the base, compute the detail by taking the difference from the original log luminance.

[a] recall why the bilateral filter is important here: see "The halo nightmare" class slide.

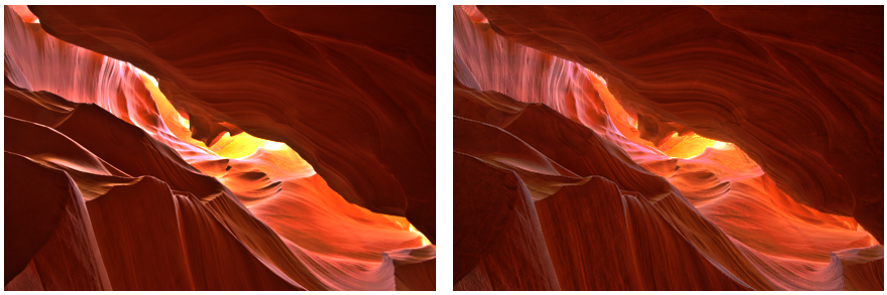
Great, you are finally ready to put everything together! Make sure you understand the slides *Contrast reduction in log domain* that combine the base luminance, detail and brightness scaling factor!

3.5. Compute the scale factor `k` in the log domain that brings the dynamic range of the base to the given target (that is, the range in the log domain should be `log10(targetBase)` after applying `k`. We have provided two new functions for you that you might find useful: `float Image::min() const` and `float Image::max() const`. Get a new base luminance using the factor, and multiply the details (in the log domain) by `detailAmp`, then add the resulting output base and detail. Make sure to add an offset that ensures that the largest base value will be mapped to 1 once the image is put back into the linear domain

3.6. Convert this new luminance back to the linear domain (you may want to separately implement `Image exp10Image(const Image &im)`). Then, reintegrate the chrominance into the resulting image. We've provided the function `Image lumiChromi2rgb(const Image &lumi, const Image &chromi)` in `basicImageManipulation.cpp` which might be helpful.

Enjoy your results and compare the bilateral version with the Gaussian one. Use the functions `testToneMapping_ante2, testToneMapping_ante3, testToneMapping_design, testToneMapping_boston` in `a5_main.cpp` to help test your tone mapping function.

Note: The bilaterial filter on the `design` image sequence takes a very long time. It is not necessary to test bilaterial filter tone mapping for this image sequence.



(a) Gaussian Tone Mapping (b) Bilaterial Tone Mapping

Figure 2: Tone mapping of the `ante2` image sequence using the parameters provided in `testToneMapping_ante2`

(a) Gaussian Tone Mapping (b) Bilaterial Tone Mapping

Figure 3: Tone mapping of the `boston` image sequence using the parameters provided in `testToneMapping_boston`

4 Extra credit (10% max)

- (5%) Deal with image alignment (e.g. the `sea` images. We recommend Ward's median method, but probably single-scale to make life easier yet slower. Alternatively, you can simulate the clipping in the darker of two images.
- (5%) Derive better weights by taking noise into account. You can focus on photon noise alone. This should give you an estimate of standard deviation (or something proportional to the standard deviation) for each pixel value in each image. Use a formula for the optimal combination as a function of variance to derive your weights. This should replace the thresholding for dark pixels, but you still need to set the weight to zero for pixels dangerously close to 1.0.
- (5%) Write a function to calibrate the response curve of a camera. See `http://www.pauldebevec.com/Research/HDR/`
- (10%) Implement the bilateral grid for fast bilateral filtering. See `http://groups.csail.mit.edu/graphics/bilagrid/` with more mathematical justifications at `http://people.csail.mit.edu/sparis/publi/2009/ijcv/Paris_09_Fast_Approximation.pdf`
- (10%) Hard: deal with moving objects.

5 Submission

Turn in your files to the online submission system (link is on Stellar) and make sure all your files are in the asst directory under the root of the zip file. If your code compiles on the submission system, it is organized correctly. The submission system will run code in your main function, but we will not use this code for grading. In the submission system, there will be a form in which you should answer the following questions:

- How long did the assignment take?
- Potential issues with your solution and explanation of partial completion (for partial credit)
- Any extra credit you may have implemented along with an explanation and their function signatures if necessary.
- Collaboration acknowledgement (but again, you must write your own code)
- What was most unclear/difficult?
- What was most exciting?