Image Processing 8

Electrical Engineering 20N
Department of Electrical Engineering and Computer Sciences
University of California, Berkeley

Hsin-I Liu, Jonathan Kotker, Howard Lei, Andrew Lee, and Babak Ayazifar

1 Introduction

Some of the most popular applications of digital signal processing occur in the growing field of image processing. Unlike audio signals, however, image signals exist in two dimensions, as opposed to one: this fact makes their processing more complicated. In this lab session, we will implement basic image processing in LabVIEW; specifically, we will focus on generating image signals in LabVIEWand extrapolate to generating two-dimensional periodic patterns. We will also employ the two-dimensional variants of several well-known one-dimensional filters on images, and explore and tweak their effects.

1.1 Lab Goals

- Extend various filters and concepts in digital signal processing to image processing.
- Explore the analogies and the connections between temporal signals and spatial signals, such as images.
- Use the file processing mechanisms available in LabVIEW.
- Use and optimize image processing algorithms.

1.2 Checkoff Points

1. Pre-Lab Section . . . .
   (a) Hexadecimal Number System: A Primer . . . .
   (b) There's an Image . . . .
   (c) All the Pretty Colors . . . .
   (d) RGB Ain't Got Nothin' On Me . . . . (2.5%)
   (e) Phantom of the Colormap . . . .(7.5%)
   (f) Submission Rules . . . .
   (g) Submission Instructions . . . .

2 Pre-Lab Section

2.1 Hexadecimal Number System: A Primer

We live our daily lives in the **decimal number system**: we do all of our mathematical operations using the digits `0` through `9`. However, for several other purposes, other number systems are much more useful. For example, you might have seen the **binary number system** before, where all mathematical operations are done using the digits `0` and `1`[1]. In the case of image processing, the **hexadecimal number system** is the most useful number system, where digits go from `0` to `9`, and then from `A` to `F`: `A` would represent the number `10` in the decimal system, while `F` would represent the number `15` in the decimal system.

DECIMAL

BINARY

HEXADECIMAL

A number written in the decimal number system is evaluated based on the following rule: the i^{th} digit (from the right) A_i contributes $A_i \times 10^{(i-1)}$ to the final value. For example, the number `12345` is equivalent to

$$(1 \cdot 10^4) + (2 \cdot 10^3) + (3 \cdot 10^2) + (4 \cdot 10^1) + (5 \cdot 10^0).$$

Analogously, a number written in the hexadecimal number system is evaluated based on the following rule: the i^{th} digit (from the right) A_i contributes $A_i \times 16^{(i-1)}$ to the final value. For example, the number `C0FF3E` is equivalent to

$$(C \cdot 16^5) + (0 \cdot 16^4) + (F \cdot 16^3) + (F \cdot 16^2) + (3 \cdot 16^1) + (E \cdot 16^0).$$

This allows us to convert from the hexadecimal number system to the decimal number system.

[1] There is a well-known joke that goes, "There are 10 types of people in this world: people who can count in binary, and people who cannot."

Moving from the decimal number system to the hexadecimal number system is slightly trickier: we will need to represent that number using a linear combination of appropriately scaled powers of 16. Thus, for example, the number `23456`, represented in the decimal number system, can be broken up as

$$23456 = (5 \cdot 16^3) + (B \cdot 16^2) + (A \cdot 16^1) + (0 \cdot 16^0).$$

As a result, `23456`, when represented in the hexadecimal number system, turns out to be `5BA0`. (Verify that this is true!)

For the rest of this lab guide, we will follow the convention that numbers in the decimal number system will be suffixed with the subscript `10`: for example, $\texttt{12345}_{10}$, while numbers in the hexadecimal number system will be suffixed with the subscript `16`: for example, $\texttt{C0FF3E}_{16}$.

Convert the following numbers between the decimal and hexadecimal number systems, as appropriate:

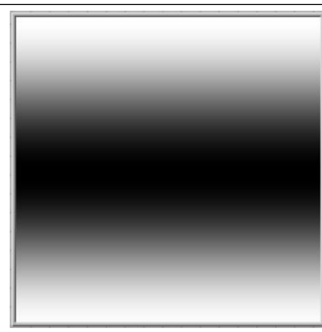
1. $\texttt{FF}_{16}$.
2. $\texttt{D3AD}_{16}$.
3. $\texttt{15}_{16}$.
4. $\texttt{15}_{10}$.
5. $\texttt{16}_{10}$.
6. $\texttt{512}_{10}$.

It turns out that numbers represented in the binary number system can be succinctly represented in the hexadecimal number system, since a collection of four **bits** (or **bi**nary digi**ts**) in the binary number system can be replaced by one digit in the hexadecimal number system. As a result, the number $\texttt{1001}_2$ can be expressed as $\texttt{9}_{16}$, the number $\texttt{1111}_2$ can be expressed as $\texttt{F}_{16}$, and the number $\texttt{10011111}_2$ can be expressed as $\texttt{9F}_{16}$.

BITS

2.2 There's an Image

Figure 1 An image where the intensity varies sinusoidally in the vertical direction.



A two-dimensional image is represented in LabVIEW as a two-dimensional array, where element (i, j) stores information about the element of the picture, or the **pixel** (**pics** + **el**ement), at location (i, j). Figure 1 shows a grayscale image, with dimensions 200 pixels by 200 pixels (under a zooming factor of 100%), where the intensity of the image varies sinusoidally. The top row of pixels in the image is white. As we move down the image, it gradually changes to black and then back to white, completing one cycle. Hence, we can state that the **vertical frequency** is $\frac{1}{200}$ cycles per pixel[2]. Similarly, the image is constant horizontally,

PIXEL

VERTICAL FREQUENCY

and so it has a **horizontal frequency** of 0 cycles per pixel. HORIZONTAL FREQUENCY

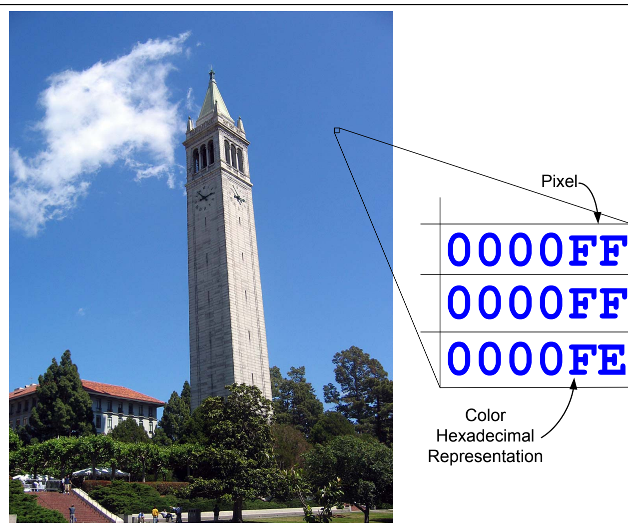
2.3 All the Pretty Colors

Colors can be represented by a **hexadecimal triplet**: three hexadecimal pairs (which is equivalent to 24 bits; why?) that are arranged in the order red, green and blue. Thus, a color of $\texttt{FF0000}_{16}$ is entirely red, while $\texttt{0000FF}_{16}$ is blue. The number $\texttt{FF}_{16}$ corresponds to $\texttt{255}_{10}$, which is $2^8 - 1$. An image is then simply a grid of these color values. This hexadecimal triplet representation is known as **TrueColor** and is shown for a few common colors in Figure 2. An illustration showing the TrueColor representations for a few pixels in an image is shown in Figure 3. This representation is also the standard for webpages: HTML, for example, utilizes the hexadecimal triplet. TRUECOLOR

Figure 2 The TrueColor representation of a few colors.

COLOR	RED	GREEN	BLUE
Red	FF	00	00
Blue	00	00	FF
Teal	38	8E	8E

Figure 3 The TrueColor representation of a few pixels in an image. (Note that the color values are not precise and are only present for demonstrative purposes.) [1]

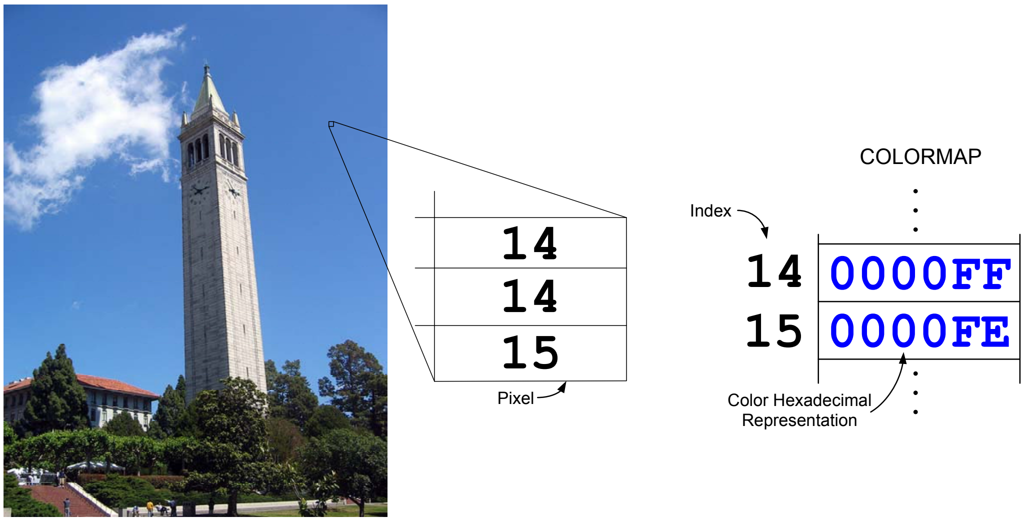


While the image blocks in LabVIEW use TrueColor by default, usually not all the colors are used. Hence, in order to conserve memory, **colormaps** are used. Colormaps provide a very simple form of image com- COLORMAPS

[2]Notice that this is a different kind of frequency than the one we normally discuss: when we talk about signals in the time domain, we are talking about **temporal frequency**; here, we are talking about **spatial frequency**.

pression. A colormap is simply a table of color values. Images will thus no longer need to hold the entire color representation, but a smaller number that references a location in the colormap. This smaller number can then be used to index into the colormap to obtain the actual color representation. This representation is called the **bitmap** representation; image files with the extension BMP are represented in this fashion: a two-dimensional array along with a colormap. An illustration of this representation is shown in Figure 4; contrast this with the basic TrueColor representation illustrated in Figure 3. BITMAP

Figure 4 The bitmap representation of a few pixels in an image. (Note that the color values are not precise and are only present for demonstrative purposes.) [1]



2.4 RGB Ain't Got Nothin' On Me

Download the `ColorRepresentation` VI from bSpace and run the VI. This VI obtains the corresponding TrueColor representation for a given color. Click on the color in `Color to Number` to change the color and see its TrueColor representation. Ignore the `Luminance` value.

For each of the colors below, determine the RGB values, and also explain briefly why the RGB values returned by the VI are intuitively the correct values. For example, green has the hexadecimal value $\texttt{00FF00}_{16}$; this makes intuitive sense because only the green component is present in the color.

1. White
2. Black
3. Orange
4. Purple

2.5 Phantom of the Colormap

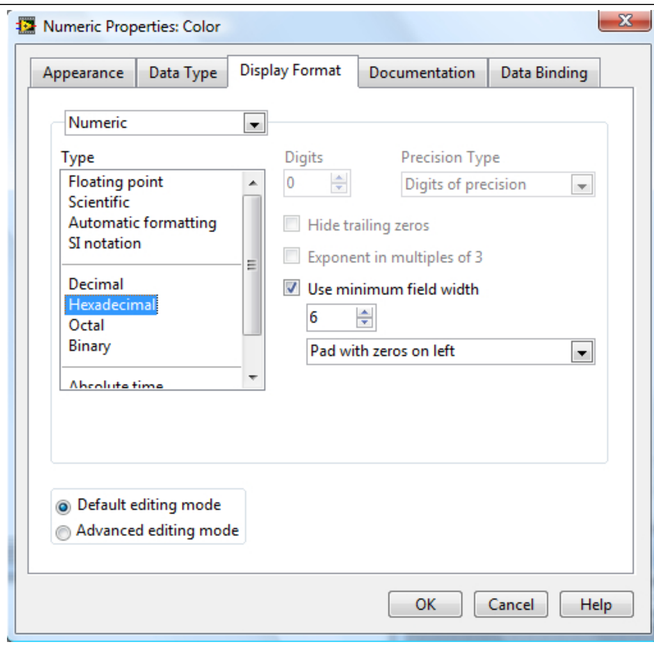
The color black has no contribution from either red, green, or blue. If we increase the contribution of all of the colors equally, we will get progressively lighter shades of gray. While the hexadecimal triplet notation provides us with the ability to represent many colors, the in-lab session will utilize a grayscale colormap.

Grayscale images use an 8-bit colormap, which can store a maximum of 256 mappings (why?) between array locations and colors. In each location in a grayscale colormap, the red, green and blue components are all equally intense. The three components each vary from $\texttt{0}_{10}$ (or $\texttt{0}_{16}$) to $\texttt{255}_{10}$ (or $\texttt{FF}_{16}$), representing 256 variations of gray. As a result, the grayscale colormap will be a mapping between the i^{th} index and the i^{th} variation of gray.

1. Create an 8-bit grayscale colormap in a VI called `Colormap`. In order to accomplish this, create an array of 256 elements. Each element should contain a color, whose hexadecimal representation has the same red, green and blue values, such as $\texttt{000000}_{16}$, $\texttt{010101}_{16}$, $\texttt{020202}_{16}$, and so on. These colors should go up to $\texttt{FFFFFF}_{16}$. You may find the `RGB to Color` block, located under `Programming` → `Graphics and Sound` → `Picture Functions`, useful; this block accepts the red, green and blue components separately, and concatenates them to produce the corresponding color. Call this array `Colormap`.

   > You will want to create an indicator for this array on the front panel. However, the indicator will, by default, choose to display the values in the array in the decimal number system. To change this, we need to first change the datatype of the array elements to be unsigned 32-bit integers. Right-click on an element, select `Representation`, and then change the datatype to `U32`. Following this, right-click again on an element in the array and select `Display Format...`. Play around with the options under the `Display Format` tab, as shown in Figure 5 so that finally, the front panel representation of each element in the array resembles a hexadecimal triplet.

Figure 5 The `Display Format` dialog box.



2. Convert this VI into a sub-VI with no inputs, but with the array generated in step 1 as the sole output.

3. Create a new VI called `Phantom`. In this VI, create a two-dimensional array of arbitrary intensities of gray. The array should have dimensions 200×200 and have values ranging from 0 to 255. If you implement this array using `MathScript`, you may find the function `rand` useful. You can also choose to generate this two-dimensional array using other blocks that involve matrix operations.

4. The `Draw Unflattened Pixmap` block converts a two-dimensional array into a picture, using a colormap to determine what color each element in the two-dimensional array corresponds to. We

will now convert the two-dimensional array that we created in step 3 to an image using the colormap that we generated in step 2. Bring a `Draw Unflattened Pixmap` block to the block diagram, and feed this array in to the `data` terminal of the `Draw Unflattened Pixmap` block.

> Make use of the in-built search functionality to determine where the `Draw Unflattened Pixmap` block is located.

5. Set the `Draw Unflattened Pixmap` block to an 8-bit representation (under `Select Type` on the right-click menu) and wire the grayscale colormap to the `color table` port on the block.

> The colormap should be explicitly specified as 8-bit, or else LabVIEW will assume that the colormap contains more values than it actually does.

6. Create an indicator for the `image` port on the front panel, and run the virtual instrument. You may need to change the size of the picture indicator to show the entire image.

2.6 Submission Rules

1. Submit your files *no later than* 10 minutes after the beginning of your next lab session, during the week of **November 5, 2012**.
2. Late submissions will *not* be accepted, except under unusual circumstances.
3. If the pre-lab exercises are not performed, you will get an immediate zero for the entire lab.
4. These exercises should be done *individually.*
5. Keep your work safe for further usage in the in-lab sections.

2.7 Submission Instructions

1. Log on to bSpace and click on the `Assignments` tab.
2. Locate the assignment for `Lab 8 Pre-Lab` corresponding to your section.
3. Attach the following files to the assignment:
   (a) Answer the questions in section 2.1 and section 2.4. Templates for this assignment are available, in DOC and TEX formats, as part of the lab 8 resources on bSpace, but you need not use them.
   (b) The `Colormap` VI.
   (c) The `Phantom` VI.

Figure 6 Love in hex. [3]

3 In-Lab Section

In the pre-lab sections, we had a chance to retrieve the RGB values for different colors and we also had a little taste of creating an image. For the most part, this lab guide relies on your creativity in implementation, so go crazy and perform the tasks in whatever manner you please, but do not forget to maintain clarity and optimality.

3.1 Do You Have Your 2D Glasses?

As we move through the lab, we will take advantage of an important and exciting idea: if we consider one row (or equivalently, one column) of an image, we are essentially looking at a discrete-time signal having various values at different points in time! Of course, we are not working in the time domain at all, but we *are* working in a discretized domain (in this case, the domain of pixels); as a result, we can utilize the ideas that we have learned through our excursions in digital signal processing to implement solutions to interesting image processing problems.

There is, however, an added complexity that comes with working with images: the *whole* image (and not just one row/column) is actually a signal that works in *two* dimensions, not one. Nonetheless, as we shall see, concepts in one-dimensional signal processing extend neatly into two-dimensional signal processing.

3.2 It's a Sine of Things to Come

1. Make a new copy of the `Phantom` VI that you created in step 3 of pre-lab section 2.5, and save it as the `Sinusoids` VI.

2. Modify the arbitrary 200 $\times$ 200 pixel image that you generated to produce an image exactly as that shown in Figure 1.

   - We know that the value of each pixel varies from `0` to `255`, reflecting the number of colors represented in the grayscale colormap. Which value corresponds to white and which value corresponds to black?
   - If done correctly, your image should match Figure 1. If the middle patch of black is too wide, this might be because the values for some of the pixels are either going below `0` or above `255`, in which case such pixels are rendered as completely black.
   - We observed that the intensities of the pixels in Figure 1 vary sinusoidally in the vertical direction from white to black, and then back to white. Using this fact, determine the mathematical function $I(i)$ that best relates row i to the intensity I of the pixels in that row. This will be the signal that you have to implement.
   - There are, of course, several ways to approach this question. However, as in previous labs, we encourage you to consider not using `For Loops`, either as structures or as constructs in `MathScript Nodes`. There are more elegant (and faster!) methods that exploit the matrix operations present in LabVIEW.
   - Again, you may find the `repmat` function useful. Also, `A'` produces the transpose of matrix `A`.

3. Duplicate the vertically varying image that you created in step 2 and modify it so that the sinusoidal variations are horizontal rather than vertical. Additionally, vary the frequency so that there are four cycles of the sinusoidal variations instead of one.

4. Duplicate the horizontally varying image that you created in step 3, and add the necessarily logic that enables a horizontal slider on the front panel to vary the frequency of the image, such that the number of cycles of sinusoidal variations can be set to any real value from `1` to `20`. Label this horizonal slider `Cycles`.

3.3 Image Processing 101

Now that we have created custom images, the next step is to manipulate images, and along the way, obtain a taster of basic image processing.

3.3.1 Living on the Edge

Continuing with our analogy of images as two-dimensional signals, we now attempt to analyze the "frequency content" of an image, although in the case of images, we talk about spatial frequency, as opposed to temporal frequency. We make the observation that parts of an image where pixel intensities vary gradually are regions of low frequency, whereas parts where pixel intensities vary suddenly are regions of high frequency. With this in hand, we then have the stunning idea that we can apply filters to images to extract images of different frequency contents, just as we apply filters to discrete-time signals to extract signals of different frequency contents!

In particular, we can apply these ideas on to the sharp edges in an image, which are, by their very nature, areas that have rich content in the high frequencies. In this section, we will see that, depending on the kind of filter we use, we can either blur an image or perform a basic edge detection algorithm.

3.3.2 2D Convolution

For one-dimensional signals, we know that every LTI filter can be uniquely represented by its impulse response. We also know the impulse response proves useful in determining the output signal of the filter, because the output signal is merely the input signal convolved with the impulse response.

Very similar concepts arise in the analysis of two-dimensional signals. For instance, we define the **two-dimensional impulse (Kronecker delta)** as the signal $\delta(m, n)$ that is 1 when m and n are *both* zero, and 0 otherwise. The impulse response of an LTI system H operating on two-dimensional signals is then defined as its response to the two-dimensional Kronecker delta, denoted by $h(m, n)$. 2D IMPULSE

Indeed, we can now go so far as to define **two-dimensional convolution**. If we have two 2D signals, $x(m, n)$ and $h(m, n)$, then the convolution of the two signals is defined as 2D CONVOLUTION

$$(x * h)(m, n) = \sum_{k=-\infty}^{\infty} \sum_{\ell=-\infty}^{\infty} h(k, \ell)\, x(m-k, n-\ell) = \sum_{k=-\infty}^{\infty} \sum_{\ell=-\infty}^{\infty} x(k, \ell)\, h(m-k, n-\ell).$$

This is, of course, the output of the LTI system H in response to the input $x(m, n)$. However, we will not attempt to manually perform 2D convolution; we will merely use functionality already present to perform it for us. Nonetheless, we need to determine what signals we need to convolve, as we will shortly.

3.3.3 Getting an Edge Start [2]

1. Download the `ImgData` VI from the lab 8 resources on bSpace. This VI will provide the image data (the 2D byte array) you will be using.
2. Create a new VI called `Image Processing`. In the block diagram, place an instance of `ImgData.vi`.
3. At the `Data` output port of the `ImgData.vi` block, you can retrieve the byte array representing an image. Using this array output, show the image on the front panel and label it as the `Original Image`. Make the picture indicator on the front panel about 250 pixels by 250 pixels. (Make sure that your `Draw Unflattened Pixmap` block is specified as 8-bit, or else your image will appear blue, and that you're using your `Colormap` VI.)

If everything is done correctly, the image should display a message. Try following what it says.

3.3.4 All a Bit of a Blur

Since sharp edges have rich content in the high frequencies, we can blur these edges simply by amplifying their lower frequency content and diminishing their higher frequency content. If we perform this across all pixels in the image, every pixel with content in higher frequencies should be affected, not just edges, resulting in the entire image becoming blurred. The filter that should now spring to mind is the low-pass filter, whose one-dimensional variant we have already seen:

$$y(n) = \frac{1}{2}\left(x(n) + x(n-1)\right).$$

Another Way of Looking at a Low-Pass Filter Notice that, from the LCCDE for a low-pass filter, the value of the output signal at every point in time is the average of the value of the input signal at that point in time, and the value of the input signal at the previous point in time; in other words, the low-pass filter essentially performs a **moving average**. With this observation, we realize that we can blur an image simply by performing a moving average over that image. For this lab, we will perform a 5×5 moving average on a given image, with the result that the intensity of each pixel in the output image is the average of the intensities of the (at most) 25 pixels in the 5×5 square centered at the corresponding pixel in the input image. Intuitively, a moving average smoothens out sharp changes in the intensities of different pixels.

How To Perform the Moving Average We will perform this moving average through 2D convolution: we will convolve our two-dimensional signal (the image) with a two-dimensional impulse response to produce another two-dimensional signal (the blurred image). The task is now to create this impulse response.

As discussed previously, the value of the output signal at any given point (m, n) is the average of the surrounding pixels in the original image within a 5×5 window:

$$y(m, n) = \frac{1}{25}\sum_{k=-2}^{2}\sum_{\ell=-2}^{2} x(m-k,\, n-\ell),$$

and in general, for an $N \times N$ window, where N is odd:

$$\begin{aligned} y(m,\, n) &= \frac{1}{N^2}\sum_{k=-\infty}^{\infty}\sum_{\ell=-\infty}^{\infty} x(m-k,\, n-\ell) \\ &= \frac{1}{N^2}\sum_{k=-\lfloor\frac{N}{2}\rfloor}^{\lfloor\frac{N}{2}\rfloor}\sum_{\ell=-\lfloor\frac{N}{2}\rfloor}^{\lfloor\frac{N}{2}\rfloor} x(m-k,\, n-\ell). \end{aligned}$$

where $\lfloor\cdot\rfloor$ is the flooring function.

So What Did You Want Me To Do? Determine the impulse response $h_{\mathsf{L}}(m, n)$ of a system H_{L} that performs the 5×5 moving average of its input, with the help of the equations from the previous paragraph.

Then, create a matrix that represents this impulse response. Note that even though the impulse response is theoretically infinite in span, you only need to create a matrix for its support (the region where the impulse response is nonzero). In this case, for example, you will only need to create a 5×5 matrix, where the pixel at $(0, 0)$ is at the center.

Finally, blur the image that you obtained in section 3.3.3 by convolving it with this impulse response, and display the output image as the `Blurred Image`. The output image should have the same dimensions as the input image.

When done, explore the blurring effect with different window sizes: 3×3, 7×7, and 9×9. You can be ambitious and include a slider that changes N, the size of the blurring window, although bear in mind that the operation becomes slower with larger blurring windows.

Helpful Tools We recommend using `MathScript Node`s to achieve the intended result, although there are blocks under `Programming` → `Array` available that are equally capable of performing the job. You may find the following `MathScript` constructs and functions useful. Use LabVIEW Help to get familiar with the functions:

1. The `conv2d` function.
2. The `zeros` and `ones` functions.
3. Recall from lab 04 that if we have n one-dimensional arrays `A1`, `A2`, ..., `An`, we can concatenate these arrays into one one-dimensional array `A` using the construct

   ```
   A = [ A1   A2   A3   ...   An ];
   ```

   Alternatively, if all of the one-dimensional arrays are of the same dimension, then we can stack these arrays one above another to create a matrix `A` using the construct

   ```
   A = [ A1;   A2;   A3;   ...   An ];
   ```

   In this context, the `;` character separates the different rows of the matrix.

3.3.5 Playing Detective

Since sharp edges have rich content in the high frequencies, we can detect these edges simply by amplifying their higher frequency content and diminishing their lower frequency content[3]. If we perform this across all pixels in the image, every pixel with content in higher frequencies should be affected, not just edges, resulting in an output image where only the edges are visible. The filter that should now spring to mind is the high-pass filter, whose one-dimensional variant we have already seen:

$$y(n) = \frac{1}{2}\left(x(n) - x(n-1)\right).$$

Another Way of Looking at a High-Pass Filter Notice that, from the LCCDE for a high-pass filter, the value of the output signal at every point in time is merely the difference between the value of the input signal at that point in time, and the value of the input signal at the previous point in time; in other words, the high-pass filter essentially performs a **moving difference**. With this observation, we realize that we can detect the edges in an image simply by performing a moving difference over that image: we determine the difference between two adjacent pixels, and if the *absolute* difference exceeds a certain (changeable) threshold, we 'let that pixel through'. This is the approach that we will be following in this section.

How To Perform the Moving Difference We will compare the intensity of each pixel to the intensity of the pixels *to its east and to its north* (where applicable), and if *either* of the absolute differences (either the difference between the current pixel and the pixel to its east, or the difference between the current pixel and the pixel to its north) exceeds a certain threshold, the corresponding pixel should be made black; else, it will be set to be white. We will also need to use a slider on the front panel to determine the threshold to be used: what are the bounds on this slider?

So What Did You Want Me To Do? Perform the basic edge detection algorithm presented above on the image that we obtained in section 3.3.3. We will do this in the following broad steps. *Read through these steps and the following section at least once before attempting them*:

1. Determine the impulse response $h_{\mathsf{HN}}(m,n)$ of a system H_{HN} that, for each pixel, determines the difference in intensities of that pixel and the pixel to its north. In other words, determine the impulse response of the system
$$y(m,n) = x(m,n) - x(m,n-1).$$
Also, determine the impulse response $h_{\mathsf{HE}}(m,n)$ of a similar system H_{HE} that, for each pixel, determines the difference in intensities of that pixel and the pixel to its east. In other words, determine the impulse response of the system
$$y(m,n) = x(m,n) - x(m+1,n).$$

2. Generate two 3×3 matrices that represent these impulse responses.

3. Convolve the input signal (the input image) with each of these impulse responses to produce two different output signals (of the same dimensions).

4. Modify the resulting signals, remembering that we need the *absolute* differences in intensities. Call these new signals $y_{\mathsf{HN}}(m,n)$ and $y_{\mathsf{HE}}(m,n)$.

5. Create a slider to manipulate the threshold, with the bounds that you determined in the previous section.

[3] Déjà vu?

6. Using the signal $y_{\mathsf{HN}}(m,n)$, generate another signal $z_{\mathsf{HN}}(m,n)$ that is `1` wherever $y_{\mathsf{HN}}(m,n)$ is larger than the provided threshold, and `0` otherwise. At this point, we have a signal that is `1` wherever the intensity of the corresponding pixel in the original image differed from the intensity of its neighboring pixel in the north by a value beyond the selected threshold. Generate a similar signal $z_{\mathsf{HE}}(m,n)$ from $y_{\mathsf{HE}}(m,n)$.

7. Finally, generate a signal z which is `1` at pixel (m,n) if either $z_{\mathsf{HE}}(m,n)$ or $z_{\mathsf{HN}}(m,n)$ is `1`.

8. We now arrive at a small technicality: the color `255` represents white, whereas the color `0` represents black. Currently, the signal z is `0` where it should be white, and `1` where it should be black. Modify the signal z to produce z', such that $z'(m,n)$ is `1` wherever $z(m,n)$ is `0`, and `0` wherever $z(m,n)$ is `1`. You can do this by subtracting the signal z from a well-chosen scalar.

9. Finally, scale $z'(m,n)$ by `255` to obtain the edge-detected output image. Display the output image as the `Edges in Image` and find an appropriate threshold for the image provided.

Helpful Tools Again, we recommend using `MathScript Node`s to achieve the intended result, although there are blocks under `Programming` → `Array` available that are equally capable of performing the job. You may find the following `MathScript` constructs helpful:

1. It is possible to compare an entire matrix pointwise to a scalar: the command `M < T` will check whether each element in the matrix `M` is less than the scalar `T`: if so, the resulting matrix will have a `1` in the corresponding position; else, the resulting matrix will have a `0` in the corresponding position.

2. Boolean operations can also be performed pointwise between two matrices. For example, the command `M | N` performs the pointwise logical `OR` of the two matrices `M` and `N`.

   The logical `OR` of `0` with a nonzero value is `1`, while the logical OR of `0` with itself is `0`.

Applications of Edge Detection Edge detection is often the first step in **image understanding**, which is the automatic interpretation of images. A common application of image understanding is **optical character recognition** or **OCR**, which is the transcription of printed documents into computer documents. Edge detection for different purposes, however, is still very much an open problem and an active area of research.

4 Post-Lab Section

In the in-lab sections, we explored the basic image processing techniques of edge detection and blurring. As part of the post-lab section, we will explore one more technique, that of removing noise from an image.

4.1 Noisy Lena

Figure 7(a) shows one of the most famous pictures in the image processing community. This image is known as *Lena*, or *Lenna*, and is a picture of Lena Söderberg, a 1972 Swedish *Playboy* model. Over the last 40 years, people have used this picture as a standard benchmark to evaluate different image processing techniques. There are some low frequency regions in the image, such as the wooden panels in the background and the shoulder of Lena; there are also some high frequency regions in the image, such as her hair and the fur on her hat. Since this image provides a good balance between its low frequency components and high frequency components, people can evaluate the behavior of their image processing algorithms by processing this picture.

Figure 7(b) shows a noisy version of *Lena*. This kind of noise is usually caused by a device error: for example, if the film becomes old or there is some dust on the lens. When this happens, engineers have to apply noise reduction techniques to restore the image.

Figure 7 *Lena*: (a) Original image; (b) Noisy image.

(a) (b)

4.2 Mean Filter Approach

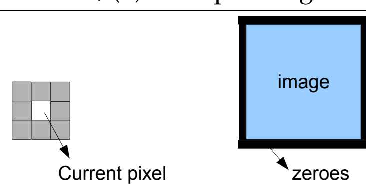
We can treat the noise of the image as an additional high frequency signal, and thus by applying the blurring function (the **mean filter**) that we introduced in the in-lab section, we can hope to average out the noise. We refine the averaging window to be 3×3 for the purposes of the post-lab sections.

4.3 Median Filter Approach

The **median filter** is also commonly used in image noise reduction. As its name suggests, the median filter takes the median value of a segment of the original noisy image. Since the noisy pixels are more likely to be outliers in an image, and thus in an image segment, we can filter out these outliers by taking the median value of the segment.

For purposes of simplicity, we will consider a 3×3 window for the median filter. In other words, for every pixel, we set its (restored) value in the new image to be the median value of its 3×3 neighborhood in the old image. In order to do that, we pad the boundaries of the image with zeros, so that the boundary pixels can be correctly processed, as shown in Figure 8.

Figure 8 The median filter. (a) 3×3 window; (b) Zero-padding the image boundaries



(a) (b)

Note that in order to determine the value of a pixel in the new image, we use the median of the 3×3 neighborhood in the *original* image; we do not perform a running median of the new image.

4.4 Submission Exercises

1. Is the mean filter an LTI system? If so, prove that it is; if not, provide a counter-example. A simple, intuitive explanation will suffice.
2. Is the median filter an LTI system? If so, prove that it is; if not, provide a counter-example. A simple, intuitive explanation will suffice.

3. LabVIEW can read and export image files, especially those in the JPEG, PNG, and BMP formats. The following exercises will require an image file in the BMP format. In a VI called `Noise Reduction`, use a `Read BMP File` block to convert an image file into a **flattened pixmap**, and then draw the picture in LabVIEW using the `Draw Flattened Pixmap` block. A flattened pixmap is essentially a one-dimensional representation of the two-dimensional image.

You need not create a control for the file input. If an input is not specified, LabVIEW will automatically prompt for a file to use at the beginning of execution. However, it is recommended to create a control for the file input, with a browse button available: to show the browse button, right-click on the control in the front panel and select `Visible Items` → `Browse Button`.

4. Convert the flattened pixmap into an **unflattened pixmap** using the `Unflatten Pixmap` block, thus allowing us to obtain the two-dimensional array representation of the image.

5. Download the noisy *Lena* BMP image, called `LenaNoisy256`, from bSpace, and provide it as input to your VI. Use the `Draw Unflattened Pixmap` block to display the noisy image in the front panel. You will need the colormap and the instructions from the pre-lab section 2.5 to display the image in LabVIEW correctly.

6. Use the blur algorithm you implemented in the in-lab section to remove the noise. Display your result on the front panel. This is the result of the mean filter approach.

7. Implement the median filter to remove the noise. Display your result on the front panel.

   (a) Note that, in `MathScript`, the `median` function needs a vector as argument. Therefore, in order to take the median of a 3×3 array, you will have to first reshape the array into a row vector.

   (b) Do not forget to pad your image with zeros along the edges! You may find the `horzcat` (`hconcatmx`), `vertcat` (`vconcatmx`), `zeros`, and `size` functions useful.

   (c) Unfortunately, for this algorithm, we will have to use nested `For Loops` in order to implement it. It may take 5 to 10 minutes to process the whole image, depending on the system running your VI. You can probe your `MathScript Node` to track the execution progress of your VI, simply by clicking on the `MathScript Node` while it runs.

8. Which algorithm of the two achieves a better performance? Conjecture why this is the case.

4.5 Submission Rules

1. Submit your answers *no later than* 10 minutes after the beginning of your next lab session, the week of **November 12, 2012**.

2. Late submissions will *not* be accepted, except under unusual circumstances.

3. These exercises are recommended to be done *in groups of at most two*. However, only one of the two persons need turn in the answers.

4.6 Submission Instructions

1. Log on to bSpace and click on the `Assignments` tab.

2. Locate the assignment for `Lab 8 Post-Lab` corresponding to your section.

3. Attach the following files to the assignment:

   (a) A text document, called `PARTNERS.txt`, containing your name and your partner's name, if any.

(b) Answer the questions in step 1, step 2, and step 8 in section 4.4. Templates for this assignment are available, in DOC and TEX formats, as part of the lab 8 resources on bSpace, but you need not use them.

(c) The `Noise Reduction` VI.

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