

Digital Filter

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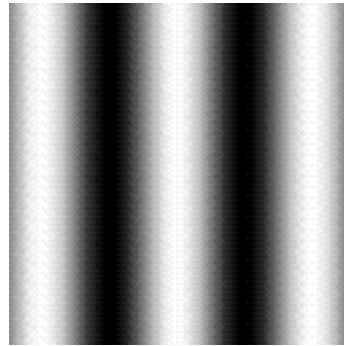
About the Program

Digital Filter illustrates the power of Fourier analysis and how it can be used to understand how the visual system processes information about shapes and forms. Digital Filter performs Fourier analyses, digital filtering, and quantization on gray-scale images. Images can be any size, limited only by available memory (and your patience). This version of Digital Filter requires an FPU (math coprocessor) and therefore will not run on a PowerMac (don't even try it) – see System Requirements below for more details.

About Fourier Analysis and Digital Filtering

On the basis of Fourier's theorem, a mathematical discovery made by the French mathematician J.B. Fourier almost 200 years ago, we can decompose any visual image into a number of **sine waves**. This procedure, called **Fourier analysis**, enables us to precisely quantify and to manipulate the spatial characteristics of a visual image.

A Fourier transform of an image (implemented here with a mathematical short-cut called the Fast Fourier Transform, or **FFT**) contains a variety of information about the image. The transform completely describes the component sine waves that, when added together, make up the image. A sine-wave grating, which resembles a series of alternating light and dark stripes with blurred edges (see figure), can be completely described by only a few parameters. The **spatial frequency** of a sine wave refers to the width of the stripes, and is typically expressed in terms of the size of their image on the retina, in cycles per degree of visual angle (c/deg). A cycle consists of one complete light-dark transition; the example figure contains 2.5 cycles. Lower spatial frequencies correspond to wider bars and higher spatial frequencies correspond to narrower bars. It is the low spatial frequencies in an image that give it its overall shape and form – the global characteristics. The high spatial frequencies contain information about edges and the finer detail – the local characteristics. **Amplitude**, or contrast, refers to the difference in luminance, or brightness, between the lightest and darkest points in a cycle. **Orientation** refers to the rotation in space. Vertical is typically 0°, horizontal is 90°, etc. **Phase** refers to the relative position of the sinewave.



A sine-wave grating

Two different image analysis techniques are demonstrated by Digital Filter. The first is **quantizing**. In order to display an image on a computer, it must first be digitized. This involves scanning the image with a device that detects and encodes the various gray levels (or colors) in the image. In the encoding process, the continuous shading in the image is translated into a fixed number of gray levels (usually 256). For each point that the scanner reads, it finds the best match out of the available gray levels. This is called **digitizing** because the continuous, or analog, changes in shading in the original are converted into discrete, or digital, values. In

addition to the number of fixed gray levels available, the quality of a scanned image is also affected by the **resolution** of the scanner. Resolution refers to the number of points digitized within a given area, and is typically measured in dots, or pixels, per inch. The higher the resolution, the greater the number of individual digital values that can be obtained in a given area.

The process of quantizing (sometimes called subsampling) is equivalent to re-digitizing an image at a lower resolution. The image is divided into a number of blocks, and the gray levels within each block are averaged. For example, if the original image were scanned at 300 dots per inch, and we quantized with a block size of 4, the resulting image would have a resolution of 75 dots per inch, or one fourth the resolution of the original.

The second image analysis technique demonstrated by Digital Filter is spatial filtering. The filtering performed here takes advantage of the principles of Fourier analysis outlined above. Because a Fourier transform breaks down an image into its fundamental components, we can manipulate those components before re-translating them back into their original form. This re-translation process is accomplished with an inverse Fourier transform, which takes a group of sine waves and builds an image out of them. The two processes are symmetrical, meaning that if you perform a Fourier transform and then its inverse, you end up with the original image. Spatial filtering involves manipulating the components before performing the inverse transform. Specifically, particular components are removed or reduced in amplitude.

The result of a Fourier transform is a set of values that represent the magnitude of each of the spatial frequency components present in an image. To filter the image, we simply change some of those values before performing the inverse transform. For example, if we wanted to remove all frequencies greater than or equal to 5 c/deg, we would set the amplitudes of those components that represent frequencies of 5 c/deg and above to zero in the transformed data. The inverse transform would then produce an image that contained no components with a frequency of 5 c/deg or above. Alternatively, rather than eliminating those frequencies entirely, we could instead reduce their amplitude, say by half. The result would be an image in which the proportion of the various frequency components was disturbed.

Spatially filtering images in this manner can give us some insight into the relative contribution of the different frequency components in an image to our perception of that image. For example, removing high frequencies reduces detail and results in what is typically called blur. However, removing low frequencies produces an image that is quite different. This process can also help us to understand how the world might appear to individuals suffering from various types of visual deficits. For example, glaucoma and the early stages of Alzheimer's disease produce a reduced sensitivity to low spatial frequencies, amblyopia and cataracts produce a reduced sensitivity at higher spatial frequencies, and multiple sclerosis produces an intermediate spatial frequency deficit.

(The preceding description was adapted from the following source: Baro, J.A. & Lehmkuhle, S. (1991). InSight 2 – InColor [computer program]. Santa Barbara, CA: Intellimation.)

How To Use the Program

Image Files

Digital Filter operates on graphics files that are stored in PICT format. PICT is a standard Macintosh file format in which virtually every color/gray-scale painting or image-processing program can save files. If

you have an image stored in another format that you would like to manipulate with Digital Filter, a program such as PhotoShop can be used to convert it to PICT format.

Digital Filter was designed to manipulate, and works best with, gray-scale images whose dimensions are a power of 2 (e.g., 64, 128, 256), and whose resolution is 72 dpi. However, any color or gray-

scale picture can be loaded and manipulated by Digital Filter. Color images will be converted to gray-scale before being displayed and analyzed. Images that are not square, or whose dimensions are not a power of 2, will be padded (filled in) to the next higher power of 2. An intermediate gray value (127) is used to pad images. With a memory partition of 3500 K, images up to 256 x 256 pixels can be analyzed.

Quantizing

The quantizing function re-digitizes an image at a resolution lower than that at which it was originally digitized. What this means is that the image is divided up into blocks and the gray-scale values within each block are averaged. The averaged blocks are then redisplayed. When you select **Quantize Image** from the **Quantize** menu, you will be asked to enter a block size. Enter a value between 2 and the size of the image that is a power of 2 (e.g., 2, 4, 8, 16). This parameter determines the size of the area over which gray-scale values are averaged when the image is quantized. The image will then be quantized and re-displayed in just a few seconds.

FFTs and Filtering

The filtering function performs a considerably more complex manipulation of the image than quantizing, and therefore may take a few minutes to complete. The image is first decomposed into its Fourier components, then some of the components are removed or reduced in amplitude, and finally, the image is reconstructed. The result is a spatially filtered image, that is, an image with certain spatial frequency components absent or reduced.

When you select **Filter Image...** from the **Filter** menu you will see two intermediate stages before the final, filtered image is displayed. The filtering process consists of the following stages: First, a Fourier transform is performed on the original image, and the transform is displayed. (If you select **Do FFT**, the process stops at this point.) In the transformed image, spatial frequency increases with distance from the center, the highest frequencies in the image being around the perimeter. Orientation is represented on the X-Y coordinates of the transformed image, orthogonal to the corresponding orientations in the original image. This means, for example, that horizontal components in the original are represented as verticals in the transformed image, and vice versa. Amplitude, or power, of the components is represented in gray scale. The FFT values are log transformed before being displayed. Smaller amplitude components are represented at the white end of the gray scale and larger amplitude components are at the black end.

Four types of filters are available for applying to an image: (1) A high-pass filter removes or reduces lower spatial frequency components, those below the specified cut-off point – it passes the high frequencies. (2) A low-pass filter is just the opposite of a high-pass filter. It passes low frequencies and removes highs. (3) A band-pass filter is composed of a low- and a high-pass filter. It removes low and high frequencies and passes a band of frequencies in the middle. (4) A notch filter is the opposite of a band-pass filter. It removes middle frequencies and passes higher and lower frequencies.

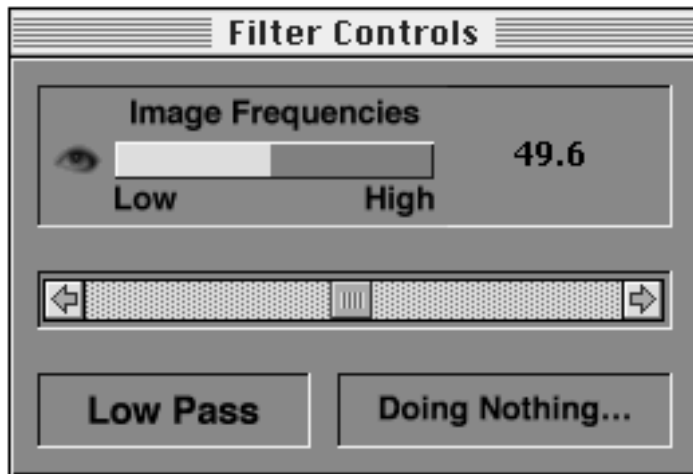
In the second stage, the actual filtering is performed. This involves reducing in amplitude (or removing, in the case of a 100% efficient filter) certain components of the transformed image. The filtered, transformed image is then re-displayed.

In the final stage, an inverse Fourier transform is performed on the filtered, transformed image. This converts the image back into the format in which it was originally displayed. The original image is then re-

displayed, minus the components reduced or removed by filtering. If no filtering were done, the inverse transform would produce the original image.

The first time a given image is filtered, the entire three-stage process is performed. However, since the Fourier transform of a given image is always the same, the first stage is not necessary for the second and subsequent filtering of the same image. This reduces the time required for filtering by almost one half.

Filter Controls



In the upper portion of the window is a white bar that indicates the range of frequencies that pass the filter. To the left, indicated by an eye, is the “Show Filter” button. To see how the currently selected filter will be applied, click and hold the mouse down in the “Show Filter” button. The frequencies removed by the filter will be erased in the FFT window. (Note: There must be an FFT window open in order to use the “Show Filter” button – if a Filtered Image window is open, just select “FFT” from the Filter menu to redraw the FFT window.) A digital value indicating the current filter setting is shown to the right of the bar. The filter settings range from 0 to 100, on a linear scale. So for example, a setting of 50 divides the entire frequency range of the image in half (the frequency range and resolution of the FFT depend on the size of the image). The scroll bar(s) below is/are used to adjust the frequency range. If you have selected a high- or low-pass filter, there will be a single scroll bar; if you have selected a band-pass or notch filter, there will be two scroll bars. The scroll bar on the left adjusts the lower end of the frequency range and the scroll bar on the right adjusts the higher end. The type of filter currently selected is shown in the lower-left portion of the window. The lower-right portion of the window shows the program’s current status (e.g., “Doing Nothing...”, “Doing FFT...”).

Menus

Open ... Opens an image, saved in PICT format, to be used for analysis. Only PICT format images will be listed in the Open File dialog.

Close xx Use the various “Close” menu items to close the image windows. These menu items will be dimmed if the specified image window is not currently open.

Save xx Use the various “Save” menu items to save the contents of the image windows. These menu items will be dimmed if the specified image window is not currently open. Images are saved in PICT format and the FFT data are saved in a plain text file.

Quit Self-explanatory.



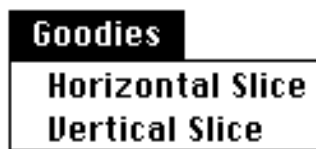
Low Pass, High Pass, Band Pass, and Notch These menu items are used to select the type of filter applied to the image. The currently selected filter is indicated with a check mark next to the menu item and in the lower-left portion of the Controls window.

Do FFT Performs an FFT on the original image and puts the result (log scaled) in a new window. Click the mouse to abort an FFT before it is completed. If an FFT has already been performed on or a filter applied to the current image, selecting this item just redraws the FFT window without recalculating the FFT.

Filter Image... Performs an FFT on the original image, applies the currently selected filter, and puts the result in a new window. Prior to beginning analysis, you will be prompted to enter a filter efficiency, in percent, between 1 and 100. This setting determines the amount of the original image that is removed. A filter with an efficiency of 100% will remove the specified frequencies entirely; a filter with an efficiency of 50% will reduce the amplitude of the specified frequencies by one half. Click the mouse to abort filtering before it is completed.

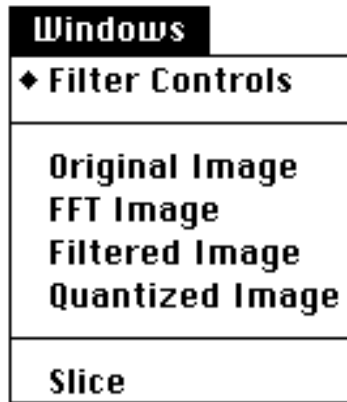


Quantize Image... Quantizes the original image. Prior to beginning quantization, you will be prompted to enter a quantization block size. The block size must be greater than or equal to 2 and must be a power of 2 (e.g., 2, 4, 8, 16). Click the mouse to abort quantization before it is completed.



Horizontal Slice, Vertical Slice These functions plot a one-dimensional slice out of the two-dimensional FFT. When you select one of these items, the cursor will turn to a cross hair and the FFT window will be brought to the front. Clicking on a row or column in

the FFT window will create an amplitude versus frequency plot in a new window. Either the positive or negative frequencies are plotted, depending on where in the FFT window you click.



Use the items in the Windows menu to select windows (in case a window is hidden by another). These menu items will be dimmed if the specified image window is not currently open.

System Requirements

You will need a color-capable Macintosh with an FPU (a math co-processor), System 7.0 or later, and a color monitor. Be sure your monitor is set to at least 256 colors or gray levels. Digital Filter requires a memory partition of about 3500 K, which means you should have at least 5 MBytes of system memory. To open images larger than 256 x 256 pixels you will need a larger memory partition, which can be set from the Finder with the Get Info dialog.

There is currently no non-FPU version of Digital Filter. Without an FPU, it takes about 6 times longer to perform an FFT – so I decided that a non-FPU version would be too slow to be usable. If you really have a need for a non-FPU version, and you have the patience to do FFTs on an LC or some other equally slow machine, let me know. Please note that, because the program makes direct calls to the FPU, it will not run on a PowerMac. As soon as I can figure out CodeWarrior Pascal, I intend to produce a native PowerMac version – it should really scream.

Update History

Version 1.1

- fixed a bug that affected scaling of the notch and band pass filters and caused the digital display of the notch filter settings to be incorrect.
- fixed an intermittent problem with window updates (I think).
- a new image can now be opened without closing the currently open image, however, following a warning, all windows related to the current image will be closed before a new image is opened.
- FFT, filtering, and quantization operations can now be aborted by clicking the mouse – current and/or previous output will be lost.
- “Show Filter” button was added to the Filter Controls window – shows how the current filter will be applied to the FFT output.

Legal Stuff

Digital Filter is released as freeware. That means that it is not in the public domain – I retain all rights, but it can be freely used and distributed as long as this document accompanies it and each remains intact (with the exception noted below). This program may not, however, be distributed as part of any commercial, for-profit exchange without my written permission. Rather than requesting a shareware fee, all I ask is that if you use the program, or think it is even slightly cool, please write and let me know (my EMail address is given below).

This program, and all future versions of it, may not be included in or distributed by the University of Michigan Macintosh archive (mac.archive.umich.edu). The reason for this restriction is their policy regarding appropriate material for the archive, and in particular, the response of one of their archivists to my submission of this program. His refusal to accept this program because it would not run on the PowerMac on which he tested it contradicts the archive's published submission guidelines: "the archivists do not have access to every software and hardware combination that a submission may require for proper functioning. Rather than penalize users for the deficiencies of the archivists, we will accept such untestable submissions on the word of the submitter if they conform to the other requirements listed in this document". I found his refusal to test my program on an appropriately configured machine inappropriate and unfortunate.

Digital Filter was written in Think Pascal, therefore portions of it are probably copyright © 1991 by Symantec Corporation.

Disclaimer

Digital Filter is distributed "as is", solely for the purpose of entertainment; any educational content or other usefulness is purely accidental. The program has no warranty, express or implied, so use it at your own risk. Please report any bugs or other problems you encounter in as much detail as possible.

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Thank you.

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