Operating Manual for DigitSeis.v.1.3

Windows Version

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This manual is provided to complement the DigitSeis.v.1.3 package for digitization of analog seismograms available on the website of the Harvard Seismology Group.

For more general information on the Harvard Seismology Group, please visit: http://www.seismology.harvard.edu/index.html.

For any questions, comments, or bug reports, please contact Marisa Reilly, Administrative Assistant, Harvard Seismology Group at reilly@eps.harvard.edu

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DigitSeis uses two functions that were not written by the authors nor are built-in functions that come with MATLAB. We have permissions from the authors to include the functions in the DigitSeis package, and they can be obtained from sources below.

`rgb2hsv_fast.m` This function was written by Dr. Alexander Ihlow (Technische Universitt Ilmenau), and is available from http://www.mathworks.com/matlabcentral/fileexchange/15985-fast-rgb2hsv/content/rgb2hsv_fast.m

`writesac.m` This function was written by Dr. David Yang (Los Alamos National Laboratory). We obtained the latest version of this function from the author, but it can also be found in the SAC distribution.
http://ds.iris.edu/ds/nodes/dmc/forms/sac/

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Contents

1 Introduction **6**
1.1 Uses for DigitSeis . . . 6
1.2 Overview of the Digitization Process . . . 7

2 Installation of DigitSeis **9**
2.1 Mac OS X . . . 9
2.1.1 Installing . . . 9
2.1.2 Running DigitSeis . . . 11
2.1.3 Uninstalling . . . 11
2.2 Windows . . . 11
2.2.1 Installation . . . 12
2.2.2 Running DigitSeis . . . 12
2.2.3 Uninstalling . . . 12

3 Loading of Images **14**
3.1 Opening DigitSeis . . . 14
3.1.1 Loading an Image . . . 14
3.1.2 Loading an Analysis . . . 15
3.2 Image Preparation . . . 16
3.2.1 Cropping . . . 17
3.2.2 Timemark Length . . . 18
3.2.3 Timemark Offset . . . 20

4 Object Classification **21**
4.1 End-Goal for Object Classification . . . 21
4.2 Point Modification . . . 23
4.2.1 Pixel Removal Tools . . . 23
4.2.2 Object Modification Tools . . . 26
4.2.3 Classification Modification Tools . . . 27

4.2.4 Checking Classification . . . 28
4.3 Region Modification . . . 30
4.4 Missing Tools in Edit Classification . . . 35

5 Trace Identification **36**
5.1 Automated Trace Identification . . . 36

6 Digitization and Correction of Traces **38**
6.1 Automated Digitization . . . 38
6.2 Correcting Traces . . . 39
6.2.1 Selecting Area for Correction . . . 40
6.2.2 Modifying Base Image . . . 41
6.2.3 Classification . . . 43
6.2.4 Digitization and Application . . . 44
6.3 Missing Tools in Correct Trace . . . 46

7 Timing **47**
7.1 Calculation of Time Anchors . . . 47
7.2 Assigning of Absolute Timing . . . 48

8 Saving Results **52**
8.1 Saving an Analysis as a .mat . . . 52
8.2 Saving a Timeseries as .SACs . . . 53

A Toolbars **56**
A.1 Main DigitSeis Toolbar . . . 57
A.2 Left Sidebar . . . 58
A.3 Edit Classification Toolbar . . . 59
A.4 Correct Trace Toolbar . . . 60

B Increased Controls **61**
B.1 Edit Classification . . . 62
B.2 Identify Traces . . . 64
B.3 Digitize . . . 68
B.4 Correct Trace . . . 70
B.5 Calculate Timing . . . 72
B.6 Extract SAC . . . 74

C Dealing with Crossed Traces **76**
C.1 Classification of Crossed Traces 77
C.2 Correction of Digitized Crossed Traces 80
C.3 Point-Fitting Option 82

List of Figures

1.1 Flow of Information Through DigitSeis 8

2.1 Open DigitSeis 10

3.1 Select Load Option Window 14
3.2 Polarity Change Window 15
3.3 DigitSeis Main Window 16
3.4 Cropping Image 17
3.5 Measuring Timemark Length 19
3.6 Set Timemark Offset 20

4.1 Classification Screen 22
4.2 Edit Classification Toolar 23
4.3 Pixel Removal Tools 23
4.4 Case for Pixel or Region Removal 25
4.5 Object Modification Tools 26
4.6 Combining Objects 27
4.7 Classification Modification Tools 27
4.8 Classification Modification Tools 28
4.9 Identifying Timemarks to check Classification 29
4.10 Example of Where Regional Modification can be Applied 30
4.11 Selection of Area for Regional Modification 31
4.12 Lowering Brightness Threshold 32
4.13 Point-Specific Modification within the Regional Modification Window 34

5.1 Trace Identification Waitbar 37
5.2 Estimated Trace Zero-Lines 37

6.1 Automated Digitization Process 39
6.2 Example of Trace Needing Correction 40

6.3 Selecting Area for Correction 41
6.4 Correct Trace Toolbar 41
6.5 Original and Masked Image 42
6.6 Isolated Image Data 43
6.7 Classifying Corrected Region 44
6.8 Corrected Region with Digital Trace Overlay 45
6.9 Comparison of Automated and Corrected Digitizations 45

7.1 Calculation of Standalone Timing 48
7.2 Setting Absolute Time for a Timemark 49
7.3 Propagated Absolute Time 50

8.1 SAC Extraction Window 54

A.1 Main DigitSeis Toolbar 57
A.2 Left Sidebar 58
A.3 Edit Classification Toolbar 59
A.4 Correct Trace Toolbar 60

B.1 Edit Classification '+' Menu 62
B.2 Trace Identification '+' Menu 64
B.3 Adjust Traces Window 66
B.4 Digitize '+' Menu 68
B.5 Correct Trace '+' Menu 70
B.6 Timing '+' Menu 72
B.7 Extract SAC '+' Menu 74

C.1 Example of Crossed Traces 76
C.2 Classified Crossed Traces 77
C.3 Separating Traces 78
C.4 Overlapping Object 79
C.5 Defining Overlapping Region 79
C.6 Combining Overlapping Segments 80
C.7 Digitized Crossed Traces 80
C.8 Isolation and Classification of Crossing Trace 81
C.9 Digitization and Application of Crossing Trace 82
C.10 Base Image with Point Fit 83
C.11 Point Fit Generated Object 84
C.12 Digitization of Point Fit 85

Chapter 1

Introduction

1.1 Uses for DigitSeis

DigitSeis is an image processing tool that will fit a digital line to the traces shown on analog seismograms in both time and location spaces. It takes a high-resolution digital scan of an analog seismogram[1] and then allows the user to create a digital copy of the information presented, which can then be extracted as time series in the .SAC format allowing for old analog data to be treated like modern digital time series. This opens up a veritable wealth of data which was previously both relatively inaccessible and had little use with regard to modern techniques.

DigitSeis is MATLAB based software[2], which, where possible, uses automated image-processing algorithms to extract data, however, it still requires human input and supervision for the purposes of correction and monitoring (and hence, this operating manual).

Please note that DigitSeis is optimized for use with seismograms that were generated without a pen (e.g., photographic type-records). The behavior of DigitSeis is not well constrained or tested for pen-generated seismograms due to the curvature introduced by the swinging armature. However, work is being done to add the capability to process these images to future releases of DigitSeis. Similarly, DigitSeis was also built around seimograms that have timemarks. In this version, changes have

[1] These images should be single scans of the *whole* seismogram, that is, multiple small scans stitched together may not work

[2] While MATLAB based, DigitSeis is provided in a standalone format where a MATLAB installation is not necessary (**Chapter 2**

been implemented to allow records without timemarks to be processed, but these are not as efficient, optimized, and well tested as the options for records with timemarks, and consequently, results may not be as accurate.

1.2 Overview of the Digitization Process

The Digitization process can be separated into the following sequence of steps:

- In the **Loading** step, the image read from the scanned analog seismogram into DigitSeis[3]. This step should also involve the cropping the image to remove spaces around traces, along with inputting a few parameters specific to each individual seismogram.
- In the **Classification** step, the image is divided into "objects" which are classified to be timemarks, traces, and noise. The user can use a multitude of tools to tweak and correct the automated classification calculation.
- In the **Trace Identification** step, the program will use the classified information in order to determine the best-guess for trace-zero lines (i.e., positions where the amplitude is zero). Again, if these need to be adjusted, this can be done so manually by the user.
- In the **Digitization** step, the user simply presses the Digitize button, and the rest is fully automated. Here the program actually fits digital waveforms to the lines on the image.
- In the **Trace Correction** step, the user can correct any issues present in the automated digitization using an area-specific tool combining the classification and digitization steps.
- In the **Timing** step, the program interpolates between timemarks in order to calculate an associated time for every point in the analysis. The user must input the absolute time for the program to reference the rest of the points from.
- In the **Saving** step, the user can finally extract the digital timeseries from the analysis as SAC files.

These steps are illustrated in the chart presented on the following page.

[3]DigitSeis works with all image formats supported by the MATLAB function `imread`, the list of which can be found https://www.mathworks.com/help/matlab/import_export/supported-file-formats.html

Figure 1.1: This chart illustrates the chronological sequence of actions which the user must take (represented by triangles) in DigitSeis along with the changing types of information (represented by boxes) being passed from one step to another. This manual is organized in a similar chronological manner to follow this process.

Chapter 2

Installation of DigitSeis

DigitSeis is available at http://www.seismology.harvard.edu/research/DigitSeis.html. It is provided as a standalone package for both Mac OS X and Windows not requiring an installation of MATLAB[1].

2.1 Mac OS X

2.1.1 Installing

The DigitSeis download will be a .zip file containing the software and all necessary dependents. To install the program, the user needs only to unzip the file[2] which will create the folder **DigitSeis**. Within this folder, the user will find another folder called **resources**[3], a **README.txt** file with instructions for installation[4], and two click-to-run shell scripts **RunInstaller.sh** and **RunDigitSeis.sh**. To install the proper MATLAB runtimes (dependencies for DigitSeis), right-click[5] **RunInstaller.sh** and select **Open**. This will bring up a warning box saying **"install" is from an unknown developer. Are you sure you want to open it?** (**Figure 2.1**). Select

[1] If the user wants the MATLAB source codes, please contact the Harvard Seismology Group (contact information is provided at the beginning of this document).

[2] DigitSeis.zip

[3] This folder should not have to be touched except in the special case outlined in the **README.txt** file found in the **DigitSeis** folder.

[4] For a standard installation, this section should be sufficient, however the user should see the **README.txt** for information on how to permanently set the proper environmental variables for their system to bypass the program launcher.

[5] Note that if a mouse is not being used, right-clicking can be achieved by clicking while holding down the Control key, or using two fingers on a trackpad.

open.[6] Doing so will open a terminal window that will display some output of the progress[7] and that can be closed once `[process completed]` is displayed (this should be the final output)[8]. This completes the installation process. As a final note on installation, please keep in mind that in order for DigitSeis to operate properly, the user must have permission to read and write to the folder where the program is installed, and where the images are being read in from.

Figure 2.1: The system warning box that will show up the first time the user tries to run either of the provided scripts. If the user double-clicks instead of right-clicking and selecting open, the **Open** option will not be available in this warning box.

[6] This only need be done the first time the script is run.

[7] this output is not particularly important, and no user interaction is required.

[8] Note that the user may modify their **Terminal** preferences to make the window close automatically by changing their settings under **Terminal** > **Preferences** > **Profiles** > **Shell** > **When the shell exits:**.

2.1.2 Running DigitSeis

To launch DigitSeis, the user double-clicks the **RunDigitSeis.sh** launcher script[9]. This will once again open a terminal window[10] (output otherwise displayed on the MATLAB Command Line will now be displayed here) and will launch the app to the DigitSeis Select Load Option Window from which an image or a saved analysis can be loaded.[11]

To close DigitSeis, the user should simply use the **x** button in the top left to close the main DigitSeis window as would be done for any window in Mac OS X. Note that if the user has not saved the analysis **Section 8.1** in the last five minutes, a warning box will appear asking the user if they really want to quit. If the user wants to go back, they just need to use the **Cancel** button, and they will be returned to the main DigitSeis window.

2.1.3 Uninstalling

To uninstall the standalone version of DigitSeis, the user just needs to delete the **DigitSeis** folder. All dependencies for DigitSeis are contained in this folder[12] and this can be considered a clean uninstall.

2.2 Windows

As a caveat, please note that DigitSeis was developed for, compiled for, and primarily tested on the Mac OS X operating system[13]. A Windows version is available, but it has not been extensively tested[14]. There are differences in appearance, and there are known cosmetic issues such as text in messages being cut off and buttons having

[9] If this is the first time the **RunDigitSeis.sh** script is being run, it must be opened with a right-click in the same way as the **RunInstaller.sh** script as was detailed in **Section 2.1** and illustrated in **Figure 2.1**.

[10] This window can be closed when the user quits DigitSeis, or the preferences mentioned in the above footnote may be modified to make it close automatically.

[11] This launcher script can be bypassed by permanently setting environmental variables (the script **RunDigitSeis.sh** temporarily sets them on each launch to work across most machines and setups) as described in the **README.txt**.

[12] This is not the case if the user has set environmental variables and moved the MATLAB runtime folder as detailed in the **README.txt**.

[13] This manual and the images within, also represent an OS X environment.

[14] It has been confirmed that the software is usable and analyses can be processed, however the testing was limited to a half-dozen analyses.

some overlap. Please note that this software remains primarily a Mac OS X software, and that as a result, support for the Windows version may be limited.

2.2.1 Installation

The installation of the DigitSeis software for a Windows operating system begins with the user downloading the file `InstallDigitSeis.exe` from http://www.seismology.harvard.edu/research/DigitSeis.html. The user then must run this script, and an installer "wizard" will guide the user through the steps of the installation[15]. The user may select where the program folder is installed, and further, may specify the option for a desktop shortcut to be created. Please note that this installation requires an internet connection in order for the software to download the necessary open-use MATLAB runtimes. Please keep in mind that as a result of these downloaded files, the final application size for DigitSeis will be around 2.2 GB. As a final note on installation, please keep in mind that in order for DigitSeis to operate properly, the user must have permission to read and write to the folder where the program is installed, and where the images are being read in from.

2.2.2 Running DigitSeis

The program may then be run like any other (including through the desktop shortcut if one was created), by clicking on the application. There is a known issue with the Windows version wherein the program may get stuck on the "Please Wait" window while saving analyses. If this occurs, please close the "Please Wait" window and then attempt to close the main DigitSeis window. If the analysis has not been saved in the last five minutes, the program will ask if you would really like to quit, select "Cancel" and then attempt to save again. If the window closes, the analysis has been saved in the last five minutes, and the user should reopen DigitSeis as they normally would.

2.2.3 Uninstalling

Should the user wish to uninstall DigitSeis, they need to run the uninstaller script which is created when the program is first installed. This script can be found in

[15] Note that dependent upon your machine and version of Windows, a user confirmation window asking for permission to make changes will appear, please select in the affirmative to continue the installation.

the following directory (starting from the directory in which the runtimes were originally installed): `uninstall/bin/win64/`. In this directory the user should find an uninstaller in the form of an executable.

Chapter 3

Loading of Images

3.1 Opening DigitSeis

When the user first opens DigitSeis, the following window will be presented:

Figure 3.1: The Select Load Option window will be the first thing the user will see after opening DigitSeis.

3.1.1 Loading an Image

If the **Open an Image** option is selected, the user is prompted to select the image which the program should load[1]. A window will pop up saying that the image is loading, and the path to the selected image will be displayed. The user will then be further prompted to select whether or not the polarity change should be considered in the following window:

[1]To follow along with this manual, the user should select the Z-component of the long-period (LP) record for February 13, 1938 through February 14, 1938 available at http://www.seismology.harvard.edu/HRV/1938.html#0214

Figure 3.2: Here the user can opt whether or not the polarity of the loaded image should be flipped, the choice should result in light traces over a dark background.

DigitSeis is built to work with images that have light-colored traces over a dark background. Therefore, if this already describes the image that is being loaded, the user should select the **No** button, whereas if the image has dark traces over a light background[2] then the user should select the **Yes** button to flip the polarity of the image. In this step, color images are also converted into grayscale through use of one of the HSV channels[3].

3.1.2 Loading an Analysis

The user can also select the **Load Existing Analysis** button from the initial load window in order to retrieve a previous analysis and pick up from where they left off. The process for saving this type of .mat analysis for loading with this option is covered in **Section 8.1**. For the purpose of the rest of this manual, the assumption will be made that a new image was loaded.

[2]e.g., light colored photographic paper with dark lines generated by exposure to light by the galvanometer.

[3]For detailed discussion of this process, see Bogiatzis & Ishii, 2016.

3.2 Image Preparation

Once the image loads, the user will be presented with the main DigitSeis window which looks like this:

Figure 3.3: Shown is the DigitSeis main window, note the loaded image (1), the toolbar (2), and the left sidebar (3).

This is the main working window for DigitSeis. As the processing of the analysis works toward completion, the user will work down the left sidebar (**Figure 3.3**) starting from the top. The associated buttons for each step will not be available until the previous step has been completed, that is, one cannot skip straight from Classification to Timing. That this order of operations is followed is crucial to the building up of the analysis in a way that will produce usable data. Therefore, as the user progresses through the process, some buttons will also become available (e.g., Identify Traces) and the user will have to make corrections to data generated in these steps with other tools. That being said, it is of utmost importance to make sure a step is completed satisfactorily before moving along in the analysis, and also that the

analysis is saved as a .mat file[4] at several points throughout the analysis. Keeping all this in mind, this manual now begins with the first step of processing.

3.2.1 Cropping

Most seismograms have a lot of space without any data (or in any case, without data which is pertinent to the digitization). For example, in the image loaded into the program shown in **Figure 3.3**, we can see that there is not only unused space where no traces are present, but also a completely different component which can be cropped out[5]. This cropping is done by selecting the **Crop Image** tool (second from left on the toolbar) which will draw a box that the user can then drag the corners and edges of to surround the area to be preserved. To crop this area, simply double-click somewhere on the screen. This is illustrated below in **Figure 3.4**.

Figure 3.4: At left is the image with a box drawn by the crop tool, and at right is the resultant cropped image showing only the traces of the vertical component.

[4]See **Section 8.1** for more information on how to save the analysis as a .mat file and the time series as .SAC files.

[5]Here we are interested in the upper recording, which is the vertical component of the seismogram, the simultaneously recorded lower portion shows the horizontal component (East-West), that is, there are essentially two different seismograms shown here, and only the top one is being considered for the purposes of this manual.

3.2.2 Timemark Length

In the next step where the program goes through an automated classification process, one crucial piece of information is the length of the timemarks. This parameter can vary from seismogram to seismogram[6], and so the user must measure and input this for each new image. Timemarks should all be roughly the same length along the horizontal axis, so only a few need to be measured so long as they generally agree. To do this, use the **Zoom Image**, **Pan Image** and **Show Whole Image** tools on the far right of the toolbar to zoom into a timemark. The user should then use **Measure Timemark Length** tool (fifth from left in the toolbar)[7] which allows the user to construct a line in *any orientation*, and returns the length in pixels of the drawn line along the *horizontal axis*. When the user has measured a few timemarks and determined a suitable length representative of the majority of the timemarks, this average value should then be inputted into the first box at the top of the left sidebar labelled **Pixels/Timemark**. This process is shown below in **Figure 3.5**.

[6]In the case where there are no timemarks, the user should input a negative value into the **Pixels/Timemark** box. The negative indicates to DigitSeis that there are no timemarks present, and it will instead calculate just trace and noise objects using the absolute value of the input as the cutoff.

[7]For more information on the different tools in the toolbar, see **Appendix A: Toolbars**.

Figure 3.5: Here the arrows indicate the three steps of measuring a timemark, (1) clicking the **Measure Timemark Length** button in the toolbar, (2) drawing a line along the length of the timemark, and (3) inputting this value into the left sidebar.

3.2.3 Timemark Offset

The other important information that must be set before proceeding is the direction of timemark offset. This simply requires the user to visually inspect the seismogram and determine whether the timemarks are offset from the traces in an upward or downward direction. This information is then passed to DigitSeis simply by setting the **Timemarks Up/Down** button in the toolbar (fourth from left) to match the offset seen in the seismogram. This is a simple toggle button, and switches back and forth between upward and downwards offset each time it is pressed[8].

Figure 3.6: Here we can see on visual inspection that the timemarks are offset below the trace (this is easily seen by looking at the topmost trace), shown in bottom right is the **Timemarks Up/Down** button set accordingly.

[8]The way this button is set will not matter in the case where there are no timemarks.

Chapter 4

Object Classification

4.1 End-Goal for Object Classification

During the Classification process, DigitSeis automatically converts the image to a binary format[1] and creates objects based upon pixels that are connected. These objects are then classified into three categories: Traces, Timemarks, and Noise. Trace objects are those much longer than the timemark length threshold[2], Timemarks are those objects whose length is around the timemark length threshold, and Noise objects are those whose length are below the timemark length threshold.

After clicking the **Edit Classification** button, the user will be presented with a wait-screen while the program computes the automatic classification described above. Once this process is finished, the modification window for the classified objects will open and display the results of the automatic calculations (**Figure 4.1**). Here, the trace objects will be displayed in white, the timemarks in blue, and noise in red[3].

[1] This is why the traces must be light on a dark background.

[2] This threshold is based on the timemark length input in the **Pixels/Timemark** box as described in **Section 3.2.2**

[3] These are default colors and can be modified along with other parameters in the Edit Classification step, for more information see **Appendix B.1**

Figure 4.1: Shown here is the window where the user can modify the objects and their classifications.

Before proceeding to the next step, the user must now go through the classification and make sure that all objects are classified properly[4]. That is, to make sure all extemporaneous objects (written notes, stains on the paper, etc...) are removed, that all timemarks are classified as so, and that all traces are classified as so. There is a suite of tools which give the user the ability to modify objects and their classifications, and they can be divided into the two categories which are detailed in the remaining part of this chapter.

[4]Note that in the top right of the Edit Classification window there is a red button and box with the default value of 85. The 85 indicates the threshold which indicates how bright a pixel needs to be to be an "object" pixel. This value can be changed (higher for more "object pixels" and lower for less "object" pixels)and the red button clicked to recalculate the classification if the classification calculated with the default value of 85 is poor.

4.2 Point Modification

The first way which we can modify the classification is by targeting individual objects, for example, a single object, or part of an object. There are several tools which we can use to do this, and these will be covered in this section while moving across the Edit Classification toolbar (**Figure 4.2**) generally from left to right.

Figure 4.2: The Edit Classification Toolbar

The first icon from the left, is to save the analysis at the current point you are at[5] and the second button from left is the regional modification tool covered in **Section 4.3**. Therefore, we begin with:

4.2.1 Pixel Removal Tools

Figure 4.3: Shown boxed are the **Line Removal** (Left) and **Region Removal** (Right) tools.

The tools shown above are important for two main tasks. The first of these is the removal of extemporaneous information, mainly noise and written notes which the fitting-algorithm need not "see". The second is for use in separating timemarks and traces which are connected and therefore classified as a single object (or isolating trace or timemark objects from noise objects). To use the **Line Removal** tool, the user simply clicks the associated button, and then holds the mouse button down while drawing a line along which pixels will be removed. This tool is best used for very small modifications and for object separation cases where the objects to

[5]See **Section 8.1** for more information on saving analysis.

be separated must be very close together even after separation. In the case of the **Region Removal** tool, the usage is similar to that of the **Line Removal** tool. The button is clicked, and the user holds down the mouse button while drawing a shape. After the mouse button is released, the endpoints of this shape will be connected to create a closed polygon. Pixels residing within this closed polygon will be removed. Both of these tools can be used multiple times until another tool is selected (e.g., the tool remains active until another option is selected, or the button is clicked again). It is also worth noting here, that all noise objects can be deleted using the button directly to the right of the brightness threshold box. In cases where there are many small noise objects, this can speed up processing considerably.

Figure 4.4: In the above case, there are written hour notes that need to be removed, along with the written date. However, in the case of the written date, care must be taken to separate the notes where they touch both a timemark and a trace object. The image shown below is an example of what this should look like after cleanup (note that the notes could have been separated and marked as noise objects, however removing objects is more memory-efficient).

4.2.2 Object Modification Tools

Figure 4.5: Shown boxed are the **Combine Objects** (Left) and **Overlapping Objects** (Right) tools.

These two tools allow for the user to modify what a "single" object is. The **Combine Objects** tool allows the user to select several objects which will then be combined and reclassified into a single object. To utilize this tool, the user first clicks the associated button and will be presented with a set of yellow crosshairs. These crosshairs are then used to click the objects which the user would like to combine (these selected objects should turn yellow). To exit the tool and finalize the combination, the user simply right-clicks or presses the ENTER key and the crosshairs should disappear.[6] The main advantages of combining objects are that it allows users to reclassify objects (e.g., using the tools described in **Section 4.2.3**) with one click as opposed to several (note, however, that these objects are line-independent in the sense that objects belonging to separate traces or non-adjacent objects should not be combined), and also that objects that are too far away from the zero position can be properly grouped. This tool is demonstrated in **Figure 4.6**.

The second tool in this category is the **Overlapping Objects Tool**. This tool allows the user to select[7]and object and then modify it's properties either adding or removing "object" pixels with tools similar to the **Region Removal** tool where areas to either add or subtract pixels are drawn. This is mainly used for processing traces who cross over one another (e.g., where pixels overlap) and more information on this process can be found in **Appendix C.1**.

[6]Note that the selection must be finalized for it to take effect.

[7]This is done in the same fashion as that for **Combine Objects**.

Figure 4.6: Shown here three separate trace objects (right side of the second line) which it would be advantageous to classify as one. This is done using the **Combine Objects** tool, and the selection of all three to combine is shown at right. To finalize their combination into one object, the user would right-click or press ENTER to leave the tool.

4.2.3 Classification Modification Tools

Figure 4.7: Shown boxed are the **Classify as Noise** (Left), **Classify as Timemark** (Middle) and **Classify as Trace** (Right) tools.

This grouping of three tools allows the user to change the classification of any object. The color of the circle in the button corresponds to the type of object, with red used to reclassify objects as noise, blue to reclassify as a timemark, and white to reclassify as a trace object. To use these tools, simply toggle the button and a pair of yellow crosshairs will appear in the classification window. These crosshairs are then used to target objects and reclassify them simply by clicking on them. To leave the tool, the user should right-click or press ENTER and the crosshairs will disappear. For example, in the image presented in **Figure 4.4**, the user could also separate the written notes and then reclassify as noise, however, it is often more efficient to simply delete noise objects rather than reclassify them since he program stores all objects

(including noise objects). However, note that objects which have been classified as noise will be masked in the Correct Trace step, and this may be advantageous in a case where the data is very noisy.

4.2.4 Checking Classification

Figure 4.8: Shown boxed is the **Identify Timemarks** tool used to check for inclusion of all true timemarks and location of extemporaneous timemarks.

Oftentimes, it can be difficult to be sure whether the all objects have been properly classified. To this end, the **Identify Timemarks** tool has been provided to allow the user to quickly scan over the classification and be able to tell if there are either too many or not enough timemarks. To turn this feature on, simply click the button highlighted above once. Once this is done, all objects which are classified as timemarks will have a yellow box drawn around them. The user can now scan across the whole classification and if the "grid" formed by the timemarks (**Figure 4.9**) seems to be missing a node, it is likely that there is an object there that should be classified as a timemark but is not. Conversely, if there is a yellow box that does not match up with the timemark "grid" it is likely that there is an object there that has been incorrectly classified as timemark. To escape this viewing mode, the user just clicks the button again.

Figure 4.9: Shown here is a screencapture depicting the yellow "grid" formed by the highlighted timemarks, note how it is easy to identify areas where timemarks should be (e.g., bottom right) and where they should not be (e.g., along the top of the classification).

4.3 Region Modification

Figure 4.10: In the above image, there are data missing that were not calculated into the original classification. To work with this part of the image the user should recalculate the classification for this specific region using the **Regional Modification** tool.

Sometimes, there are cases where areas of a classification (as opposed to single objects) need correction or where there are missing data (**Figure 4.10**). It is often less labor intensive to take care of these areas by recalculating the classification for a selected region[8] then by using the point-specific methods and tools described above. To do this, the user needs to use the **Region Modification** tool, whose icon is second from left in the Edit Classification toolbar.

After selecting this tool, the user will need to drag a box around the region for which they would like the classification recalculated, and double click anywhere on the screen in order to finalize and select this region[9]. After this is done, the Analyze Small Image Patch window will pop up with the recalculated classification for the selected region.

[8]This is done in a method similar to how the original whole-image classification was done, but only taking into consideration the brightness of the pixels in the selected region.

[9]The box can be resized until the user double-clicks.

Figure 4.11: Shown at top is the box used to select the region from **Figure 4.10** where there are missing/incomplete objects. Shown below is the Analyze Small Image Patch window which displays the new classification for this particular area.

It can be seen that there has been some data recovered in the recalculated region, however, it still misses some of the data. To remedy this, the brightness threshold above which pixels are defined as being objects can be modified. This can be done by modifying the number in the box in the top right of the window and pressing the red button to the left of the box. The default value in this box is 85[10], but the user can increase the data pixels by lowering this number (**Figure 4.12**).

Figure 4.12: When comparing the above image with that of **Figure 4.11**, lowering the brightness threshold to 80 brought out nearly all of the data that were "missing."

[10]This means that the brightest 15% of pixels are considered object pixels.

Once all the data exist as objects[11], the user can make further changes using the same point-specific modification tools which were described in the previous section (note that these tools are also present in the Analyze Small Patch Window). In the case shown in **Figure 4.13**, after lowering the brightness threshold enough to have all data present, there were timemarks which had to be separated.

The user should also note the presence of a few new tools in the Analyze Small Image Patch window. The first tool from left in the toolbar is the **Cycle Mask** button which switches between, the masked (modified) image and original image. This button is used when viewing the underlying image, which can be done with the eighth button from left. This is the **Show Classification** button which switches the view between the classified objects and the underlying image. If the user desires to bring part of the original image back to the masked version, they should use the second button from left (**Region Recovery** tool) which allows them to draw polygon whose interior will be recovered.

When the selected region has been processed satisfactorily, the Apply button can be used to export these changes back into the main classification. By combining this method with those described in **Section 4.2**, the user should go through the classification until they have deemed it satisfactory. Users should keep in mind that the classification stage is the most time-intensive and important step in the analysis process and so one should not hesitate to take their time with this stage. When the whole classification is completed, the Edit Classification window can be closed, returning the user to the main DigitSeis window.

[11] It is worth noting that this is actually a small earthquake logged into the station records.

Figure 4.13: After the brightness threshold reduction demonstrated previously, the user now separates timemarks from trace in the Analyze Small Image Patch window in a manner identical to that detailed in **4.2**.

While the steps and tools described in this chapter are perfectly sufficient for handling most analyses, there are other tools which allow the user further control over what the computer is doing during the automatic classification calculation. These controls are detailed in **Appendix B.1**. Also, read **Appendix C: Dealing With Crossed Traces** for information and tips on how to handle classification of objects that overlap many other objects.

4.4 Missing Tools in Edit Classification

The **Edit Classification** step is the most complex of the process and as a result, there is a lot going on. To keep the program from becoming confused, sub-windows must be closed, and processes completed before the user is allowed to do anything else. Therefore, if tools become unavailable during the **Edit Classification** step, the user should check for the following situations (in the given order):

- The small region classification window is still open.
- The overlap analysis window is still open.
- The object selection or combine object process has not completed.
- Processing is slow (e.g., after removing a region) and after the process is completed, the tools become available. In this case, the user might want to restart the program/computer.

Chapter 5

Trace Identification

5.1 Automated Trace Identification

Once the classification stage of the analysis has been satisfactorily completed, the next step is to have the program estimate the zero-lines of the traces based on the positioning of the objects defined previously. These trace-zero lines are important as they are the basis for the digitization that occurs in the next step[1]. To begin the process, the user simply needs to click the **Identify Traces** button on the left sidebar[2]. The program will display a waitbar showing the progress (**Figure 5.1**), and when it is complete will display the estimated zero-lines as dotted lines overlaid on the image (**Figure 5.2**).

In **Figure 5.2** note how the dotted lines line up right on top of the traces which they represent. This is the ideal case. In some cases where there is more curvature to the traces[3], the trace-zero lines may be slightly off at the ends. However, if there are either too many trace-zero lines, too few trace-zero lines, or simply lines offset to an unacceptable degree, the user must manually modify the trace-zero lines. See **Appendix B.2** for information on how to manually set the trace-zero lines.

[1]The zero line provides the backbone from which the algorithm looks to either side to find objects that belong to this particular line. This zero-line will also determine the amplitude of the waveforms and will provide a basis for time calculation in a analyses without timemarks.

[2]Recall that as the user works through the analysis, they will proceed down the left sidbar

[3]The trace-zero line is assumed to be a quadratic polynomial function.

Figure 5.1: The waitbar showing progress on trace identification. The user should be patient as this may take a few minutes.

Figure 5.2: Shown above are the estimated trace zero-lines calculated by the program.

Chapter 6

Digitization and Correction of Traces

At this point in the analysis, all the classification work can now be turned into something more tangible in the way of actual digital lines representing the data on the image. Once again, there are two stages to this part of the analysis. First the program takes the classification information and trace zero-lines provided in the previous steps and does its best to fit digital lines to the image. After this, the user can go and make any corrections that may be necessary.

6.1 Automated Digitization

To begin the automated portion of the digitization process, the user needs only to click the **Digitize** button[1] below the **Identify Traces** button in the left sidebar, doing so will initiate the automatic digitization process[2]. As the work progresses, each line that has been digitized will have its digital trace overlaid on the image and trace-zero line in a blue color. Once all of these traces have populated, the process is finished. If this is not the first time the traces are being digitized, then a table will appear after the **Digitize** button is pressed that will prompt the user to select which traces to re-digitize[3]

[1]The user should again note the presence of a + button which allows for increased controls covered in **Appendix B.3**.

[2]The program also attempts to vertically offset the timemark objects to merge smoothly with the trace objects in this step

[3]There is a button on the bottom of this table that allows the user to simply select all traces for re-digitization.

Figure 6.1: Shown above is the automated digitization algorithm of the program progressing its way through the image and overlaying digital traces.

6.2 Correcting Traces

Once the automated portion of the digitization process has finished, it is up to the user to carefully go over the seismogram to make sure that the program has successfully captured all the data visible on the image. If the seismogram is "easy" in the sense of having no crossed traces and not being particularly noisy, the automated digitization often captures all data present. However in many cases, the user must make small tweaks to correct the automatic digitization (**Figure 6.2**)[4]. Oftentimes, these can be found by checking the **Find Gaps** button at bottom of the left sidebar, which will draw yellow boxes around gaps in the digitized traces.

[4]The keen reader will recall that this issue was actually corrected as an example in **Section 4.3**, however, this will once again serve as an example of another way traces are corrected.

Figure 6.2: Note in the above trace how the digital trace clearly does not capture all the data present in the image.

6.2.1 Selecting Area for Correction

To select the area to be corrected, the user needs to click the **Correct Trace** button. This will bring up a set of yellow crosshairs[5] which the user should use to select a point on the trace-zero line for the trace they would like to correct[6]. Once this point has been selected, the crosshairs will disappear and a box with movable borders will be drawn, the user can drag these borders until the region which they would like to correct is fully within the box[7]. Double clicking this box will open up the Correct

[5]This may take a few seconds. Note also, that while the crosshairs are loading, tools will be unavailable and continue to be as such until an item has been selected. As a result, if the **Correct Trace** button is selected unintentionally, the user must still select an item to correct and then close the resultant sub-window in order to regain access to tools.

[6]Trace Correction is a trace-specific procedure, and can only deal with one trace or parts of one trace at a time.

[7]With regard to Trace Correction being trace-specific, this box can contain more than one trace, however any data not belonging to the trace that was initially selected will need to be deleted. This sort of operation will be necessary in cases where corrections are being made on traces that cross

Trace window[8] where the user will repeat a regionally specific version of the process which has been used so far on the whole trace: editing the base image, classifying objects, and digitizing.

Figure 6.3: Shown here is the area that should be corrected within the bounds of the box.

6.2.2 Modifying Base Image

Figure 6.4: Shown above is the toolbar of the Correct Trace window. Most of these tools should look familiar to the user.

over one another (dealing with crossed traces is covered in **Appendix C: Dealing with Crossed Traces**).

[8]The user should look at the name of the window for confirmation that they are indeed correcting the intended trace.

The first thing that the user will need to do is to modify the base image to isolate the data of interest. There are several tools available to the user to allow this. In the fifth and sixth positions from left, note the familiar **Line Removal** and **Region Removal** tools from **Chapter 4**. New tools in the third and fourth positions from left[9] are the **Cycle Mask** tool and the **Region Recovery** tool, respectively. The **Cycle Mask** allows the user to cycle between the masked image (that modified by removal of certain areas) and the original image (**Figure 6.5**). The **Region Recovery** tool is the opposite of the **Region Removal** tool, as it allows the user to select a region where data will be recovered from the original image and reinserted back into the masked image, this is especially useful for when too much of an area is removed. The user should use these tools to isolate the data of interest as shown in **Figure 6.6**.

Figure 6.5: Shown above at left is the masked image (the dark regions are what DigitSeis knows to be parts of other traces or noise), at right is the original image. The user can switch between these two views using the **Cycle Mask** tool.

[9]The first two tools are used for an alternative spline fitting method for digitizing traces. This method is covered in **Appendix C: Dealing With Crossed Traces**.

Figure 6.6: Shown here is the masked image after connected segments were separated and missing regions recovered.

6.2.3 Classification

Once the image has been cleaned, the user can reclassify the objects present in the selected region. To do this, the **Calculate and Show Classification** button (ninth from left, and to the left of the three familiar **Classification Modification** tools). Selecting this option will take the user into an Edit Classification-style screen where the classification of objects can be changed using the **Classification Modification** tools covered in **Section 4.2.3**. Note that areas and lines can still be removed in this classification view if objects are touching, also note the presence of the **Overlapping Objects** tool which is used in the same way as was described in **Section 4.2.2**. It is also sometimes necessary for the user to modify the brightness threshold as described in the latter half of **Section 4.3** (this box and red button are once again present in the top right corner of the window).

Figure 6.7: Shown here is the correctly classified selected region, the process used here is nearly identical to that described in **Chapter 4**.

6.2.4 Digitization and Application

The final step before the selected region can be merged back into the main analysis is to re-digitize the trace. To do this, select the **Digitize** button in the Edit Trace toolbar (**Figure 6.4**) (thirteenth from right, and marked with a "D"). Clicking this button will digitize the objects the user has classified and overlay the calculated digital trace onto the objects[10]. The user can also use the **Set Vertical Offset** button (to the right of the **Digitize** button), in order to tell DigitSeis how much it should vertically offset the timemarks to merge smoothly with the rest of the trace the **Gradient Minimization** button will reset the offset back to the default, otherwise the numerical offset can be changed manually until the user is satisfied.

To merge this corrected region back into the main analysis, the user selects either the **Apply Skip NaN** button or **Apply Include NaN** button, both located in the bottom left of the window. Both will merge the correction and main analysis, but the user must select whether to include NaN values (resulting in gaps in the digital trace) or ignore NaN values (previously digitized traces in these positions will be preserved).

[10]If this overlay is not what the user expects, then the user must go back and re-modify the image and classified objects until the desired result is achieved.

Figure 6.8: Shown above is the digital trace overlay calculated with the **Digitize** tool, the digital trace now captures all the data present and can be remerged with the main analysis. Because there is no gap in the trace, the two **Apply ...** options have the the same result.

Figure 6.9: Here, the corrected digital trace from **Figure 6.8** has been merged back into the main analysis (Above Right) and compared to the original automated digitization (Above Left).

6.3 Missing Tools in Correct Trace

Much like the **Edit Classification** step, there is a lot happening during the **Correct Trace** step, and as a result, there are cases where tools may not be available in the expected fashion or time. Once the **Correct Trace** button is clicked, all of the pushbuttons on the left sidebar become disabled until the **Correct Trace** routine is completed. Therefore, if these buttons are unclickable, the user should try the following remedies that commonly cause this to happen.

- Wait a few seconds to see if the yellow crosshairs appear on the screen. If they appear, then the **Correct Trace** routine has been begun. If this was unintentional, simply select a trace, double-click on the region selection box, and then close the resultant Correct Trace sub-window.

- Check to see if there is a box somewhere in the main DigitSeis window. This indicates that the **Correct Trace** routine has begun, and a trace has been selected. Once again, if this was unintentional, simply double-click the box to open the Correct Trace sub-window and close it to complete the **Correct Trace** routine.

- Check to make sure there is a not a Correct Trace window open (note that this may be behind the current main DigitSeis window). Close this window to complete the **Correct Trace** routine, and the tools should once again become available.

Chapter 7

Timing

At this point, digital waveforms have been generated and corrected to be accurate reproductions of the data displayed on the analog seismogram. However, that leaves one crucial component still missing, the timing[1]. To generate digital time series, each data point must have a time assigned to it. To begin the timing process, the program must first calculate time anchor locations for the trace by using the timemarks and ends of the traces. These anchor locations then have absolute time assigned to them. The steps the user must take to do this are described in the following section. Before proceeding, note again that while DigitSeis has the capability to process records with no timemarks, these features are not yet optimized and may not produce results with the same accuracy as is seen on records with timemarks.

7.1 Calculation of Time Anchors

The timing anchor calculation is an automated process. The user needs to initiate this process by clicking the **Calculate Timing** button[2]. This will open a waitbar showing the progress of the calculation. As the calculation progresses, the main DigitSeis window will be populated with time anchors appearing as yellow "timebars" within traces[3] and as red "timebars" at the ends of each trace.. When this is finished, the waitbar will close and the **Calculate Timing** button will change to an un-

[1] At this point in the analysis, the digitized traces are expressed in terms of x and y coordinates as opposed to being expressed as a time and amplitude.

[2] If the **Calculate Timing** button is unavailable, check to make sure that all windows associated with the **Correct Trace** step have been closed.

[3] These correspond to the identified timemarks and will not appear in analyses which do not have timemarks

clickable **Update Time** button.

Figure 7.1: As the time anchors are calculated, the waitbar will progress and "timebars" will populate in yellow and red.

After the time anchors have been populated, the user should go through the analysis and make sure that the yellow "timebars" correspond properly to timemarks and red "timebars" correspond to the ends of the lines. If these locations are inaccurate, the user can move the "timebars" to reset the anchors. This is important as these will define the accuracy of the absolute timing[4].

7.2 Assigning of Absolute Timing

Once the time anchors are satisfactorily placed, the user must tell DigitSeis what time to assign to the anchors. This is done by right-clicking one or more of the

[4]Note that at this time there is no way to add a yellow "timebar", but moving a red one off of the end of the trace will cause a new yellow "timebar" to appear.

"timebars" and setting the absolute time to which it corresponds. Doing this will then allow DigitSeis to extrapolate from that one absolute point to the rest of the seismogram. The written notes[5] can often be helpful for knowing what timemarks correspond to what absolute times. In the case of an analysis without timemarks, two of the red "timebars" at the ends of traces should be set[6].

Figure 7.2: Shown above left is the right clicking of the 15:00 hour mark (this is indicated by the written notes) and shown at right is the inputting of this time into the Set Reference Time box.

Once the time for a timebar has been set, the time will be displayed next to the timebar in red. Once the minimum number of times are set[7], the **Update Time**

[5]While these may have been deleted from the classification, they should still be present on the original image which everything is overlaid atop.

[6]Recall that these types of analyses did not have yellow "timebars" calculated, that is, the only time anchors are at the ends of traces.

[7]Analyses with timemarks only need one timebar or any color to be set, analyses without timemarks require two red timebars to be set (movable yellow timebars will propagate after **Update Time** is clicked.

button will go from grayed-out and un-clickable to red and clickable. This button should now be used to assign absolute timing from the reference point(s) to the rest of the seismogram. When clicked, the absolute time will be displayed every 15 minutes in the analysis as is shown in **Figure 7.3**.

Figure 7.3: Shown here is the absolute time extrapolated from the reference point(s) to the rest of the analysis with 15-minute markers in yellow. Note that the timebar for the original reference point is brighter and bolder. Also note that the 15-minute marks align vertically.

Once again, it is important that the user checks over the work of the program to make sure that the absolute time has been calculated properly. This can be done by making sure that the 15-minute marks all line up vertically[8]. If this is not the case, the user needs to define another reference time point someplace on the problematic

[8]That is, that each trace is an integer multiple of 15 minutes, which should be the case because traces are typically one-hour long, therefore, 15-minute marks should all be in the same positions and should form columns (these may have some shift, but not large jumps).

trace and **Update Time** again. If need be, this can be done (though this should seldom be necessary) for every trace to get all of the 15-minute marks to line up properly.

Chapter 8

Saving Results

There are two very different ways that data can be saved from DigitSeis. One is used to save the analysis so that the user can leave and come back later to pick up where they left off or make a correction. The second is used to extract the finalized data in SAC format for use like any other modern time series. These two methods are covered in this order in the following two sections.

8.1 Saving an Analysis as a .mat

This section has been referenced a few times previously in this manual, and with good reason. Saving analyses as .mat files is the way the user can save work in the DigitSeis and return to where they were if they are not yet at the point where .SAC files can be extracted. For that matter, even after .SAC files can be extracted it is often prudent to save the completed analysis as a .mat file so that it can be reopened with DigitSeis and used to generate the .SAC files again should anything happen to the original copies. That being said, executing this type of save is extremely straightforward. In both the DigitSeis main window and the Edit Classification window, the first icon from left in the toolbar is a blue save icon. The user need only click this icon and tell DigitSeis where the .mat file should be saved. A window asking the user to wait while the save is in progress will pop up and disappear when the save is complete. There are several times where it is recommended that the analysis is saved in case of mishap further down the line. These are as follows:

- After the image has been loaded and cropped
- After classification has been completed (for more complicated and in depth seismograms, it may be a good idea to save several times throughout the clas-

sification process)

- After traces have been digitized
- After traces have been corrected (again, if this is a complicated analysis requiring many corrections, several saves throughout this stage would be sensible)
- After timing has been completed

Note that if the save icon is inactive there are several possibilities for why this might be the case. These are as follows:

- The analysis is currently being saved. Please wait a few seconds until the processing is complete.
- The trace selection function in **Correct Trace** has been initiated. Complete the **Correct Trace** routine (**Section 6**, esp. **Section 6.3**).
- The identify trace function is in process. Let the process complete.
- The digitization function is in process. Let the process complete.
- The time calculation function is in process. Let the process complete.

As a final note on .mat files generated by DigitSeis, it is worth mentioning that this version of DigitSeis is completely back-ward compatible in the sense that files generated by earlier versions will open without any problem. However, note that files saved in DigitSeis.v.1.3 will not be compatible with earlier versions of the software.

8.2 Saving a Timeseries as .SACs

When the classification, digitization, and timing are all complete, all the components of a complete and modern digital time series are there. Now, all that must be done is to get this timeseries out of DigitSeis and into a form usable for modern analysis techniques. To do this, the user just needs to utilize the **Extract SAC** button at the bottom of the left sidebar[1]. This button will bring up another window asking for station information that is included in the .SAC files (**Figure 8.1**). After these are filled out, all that needs to be done is click the **Generate SAC Files** button and select the location for DigitSeis to write the .SAC files in.

[1]Now that the timeseries is finished and ready for extraction, note that we've worked our way to the bottom of the left sidebar!

Figure 8.1: The window where the user can input station information for inclusion in the SACs.

Appendix A

Toolbars

In this appendix, explanations are provided for the tools in the various toolbars used throughout the digitization process.

Explanations will be brief, however for the most important tools, references to the main body of this manual will be provided telling the user where to look to find more information on their use.

This appendix is not a quick-start guide and should mainly be used as a reference to refresh the memory on what tools do what. It is highly recommended that the user read through the main body of this manual in its entirety as it will provide the best walkthrough of how to use DigitSeis.

A.1 Main DigitSeis Toolbar

Figure A.1: The Main DigitSeis Toolbar

From left to right, the tools in the Main DigitSeis Toolbar are as follows:

- The **Save** icon allows the user to save the analysis as a .mat file (**Section 8.1**)
- The **Crop** tool allows the user to select area to crop (**Section 3.2.1**)
- The **Undo** button allows the last action to be undone (when clickable)
- The **Timemarks Up/Down** toggle lets the user define the direction which timemarks are offset in (**Section 3.2.3**)
- The **Measure Timemark Length** tool allows the user to measure horizontal length of objects (**Section 3.2.2**)
- The **Curved Offsets** tool allows the user to define and correct curvature from pen-style seismograms[1]
- The **Show Point Time** tool allows the user to click anywhere on a trace and see what the absolute time that has been assigned to that point (becomes available after traces have been timed)
- The **Zoom** buttons allow the user to both zoom into and out from the image in the main DigitSeis window
- The **Pan** button allows the user to move the image in the main DigitSeis window by dragging
- The **Show Whole Image** button allows the user to snap back to the whole-seismogram view

[1]This feature would be used in the case of seismograms generated with an armature (hence the curvature) and reflects functionality that has not yet been fully developed.

A.2 Left Sidebar

Figure A.2: The Left Sidebar

The Left Sidebar is the main "control panel" for DigitSeis. As the user progresses through the analysis of a seismogram, they will also progress downwards along the length of the Left Sidebar. In fact, the chapters of this manual are essentially organized in the same order as the different options present on the Left Sidebar.

This chronological order is as important for this document as it is for DigitSeis itself, and this is why certain options in the Sidebar will populate only at certain times or after certain actions have been taken. In this case, all the options have been enabled for better viewing. However, in practice there will not be a time when all options are enabled as is illustrated at left.

What is most important to note about the left sidebar aside from its directionality is the presence of the + buttons on most of the options. These buttons will open menus that will give additional controls over the steps they are paired with. These menus and their options can be considered "Advanced Features" and provide controls sometimes necessary for more complicated analyses, these are covered in detail in **Appendix B: Increased Controls**.

A.3 Edit Classification Toolbar

Figure A.3: The Edit Classification Toolbar

The Edit Classification toolbar is slightly different from the Main DigitSeis toolbar with some Classification-specific tools. The tools from left-to-right are as follows:

- The **Save** icon allows the user to save the analysis as a .mat file (**Section 8.1**)
- The **Regional Modification** tool allows the user to select an area over which to recalculate and make changes to the classification (**Section 4.3**)
- The **Line Removal** tool allows the user to draw a line along which object pixels will be removed (**Section 4.2.2**)
- The **Region Removal** tool allows the user to draw a polygon inside which object pixels will be removed (**Section 4.2.1**)
- The **Combine Objects** tool will allow the user to select multiple objects to combine as one (**Section 4.2.2**)
- The **Overlapping Objects** tool allows the user to add or remove pixels, and define pixels that belong to multiple objects (**Section 4.2.2** and **Appendix C.1**)
- The **Undo** button allows the user to undo the last action taken
- The three **Classify as ...** tools allows the user to select an object to reclassify as either noise, timemarks, or traces (**Section 4.2.3**)
- The **Identify Timemarks** tool will draw yellow boxes around all timemark objects (**Section 4.2.4**)
- The **Zoom**, **Pan**, and **Show Whole Image** buttons have the same function as those in the Main DigitSeis Toolbar (**Appendix A.1**)

A.4 Correct Trace Toolbar

Figure A.4: The Correct Trace Toolbar

Icons in this toolbar from left to right are:

- The **Spline Fitting** option allows the user to place points over the image and fit a curve through them (**Appendix C.3**)
- The **Spline Object Generation** tool generates objects from the splines fit with the **Spline Fitting** tool (**Appendix C.3**)
- The **Cycle Mask** toggle allows the user to go between the masked and original image (**Section 6.2.2**)
- The **Region Recovery** tool allows the user to draw an area in the masked image to recover the original image in (**6.2.2**)
- The **Region/Line Removal**, **Overlapping Objects**, and **Undo** tools have the same function as in the Edit Classification toolbar (**Appendix A.3**)
- The **Calculate and Show Classification** button will calculate a classification from the modified image and switches between the view between the masked image and classified objects (**Section 6.2.3**)
- The three **Classify As ...** tools have the same function as in Edit Classification (**Appendix A.3**)
- The **Digitize** button will calculate the digital line (**Section 6.2.4**)
- The **Set Vertical Offset** tool allows the user to manually define the timemark offset distance or find the vertical offset resulting in the smoothest transition from trace to timemark (**Section 6.2.4**)
- The **Zoom**, **Pan**, and **Show Whole Image** buttons have the same function as those in the Main DigitSeis Toolbar (**Appendix A.1**)

Appendix B

Increased Controls

In this appendix, the menus allowing for increased controls over different parameters DigitSeis uses (accessible via the + button to the left of the different major steps in the left sidebar) are covered. These parameters have been optimized and many simple seismograms should be processable without needing to use any of these controls. This simple and straightforward type of digitization is detailed in the main body of this manual.

However, there are cases where these parameters will need to be modified in order to successfully digitize more complicated or difficult seismograms. That being said, it is highly recommended that the user be very comfortable with the standard digitization process (i.e., that described in **Chapter 1** to **Chapter 8**) before moving to these more difficult analyses.

Finally, as a word of warning, it is best to modify no more than a few parameters at a time[1], this way, the direct result of changing this parameter can be observed. Also note that all of the increased controls menus have **Save** buttons in the bottom right. These will save the parameters as they are shown as the new defaults *for every subsequent analysis*[2]. That being said, it would be prudent to make notes of what the default values are before making program-wide changes with the **Save** button. As a final caution, there are a few parameters which are included in these menus but should generally not be modified. These will be marked with a: ☣

[1] This is especially true if this is the first time the user is modifying these parameters!

[2] Simply changing the parameters and not using the **Save** button will keep these changes analysis-specific with the changed parameters only being used when this analysis is opened.

B.1 Edit Classification

Figure B.1: + Menu for Edit Classification

In the + menu for the Edit Classification stage, the user can change several parameters relevant to the automatic calculation of classification[3].

In the uppermost group of three boxes, the **Image threshold (%)**[4] controls the cutoff level for which pixels are defined to be "objects". For example, with the current setting of 85, the brightest 15% of pixels will be considered "object" pixels. The **Threshold Range**(✱) parameter is a "wiggle room" factor modifying the **Image threshold (%)** parameter. The **Minimum number of pixels** parameter controls the number of object-pixels that must be grouped to be defined as an object[5].

The **Classification Colour Scheme** box allows the user to set what colors trace, timemark, and noise objects appear in.

The **Small Classification Window Setup** grouping of parameters allows the user to set the bounds for the size of the Regional Modification (**Section 4.3**) and Overlap Traces (**Section 4.2.3**) sub-windows[6].

When calculating the automatic classification, DigitSeis divides the image into small patches and calculates the objects for each independently. The **image x division** and **image y division** parameters control how the image is divided into the patches.

Finally the **timemark length perturbation for classification**(✱) parameter is a "wiggle room" factor which modifies the **pixels/timemark** parameter set in **Section 3.2.2**.

[3]This is touched on in **Section 4.1**.

[4]This parameter can also be easily modified in the Edit Classification window, as well as the Modify Region window with value shown at the top right corner of the windows.

[5]Take caution if lowering this parameter, as it may lead to a very large number of objects being created which will eat up memory and slow down the program.

[6]These can be manually changed after they pop-up, but the user may desire that the window always pop up in a certain place and be a certain size to begin with.

B.2 Identify Traces

Figure B.2: + Menu for Trace Identification

The first and only parameter in this + menu is the **number of vertical strips to be considered** box whose default value is 15. This controls the number of segments or strips that the program looks at when estimating trace zero lines. For seismograms that result in trace-zero lines that span two different traces, this number needs to be raised.

There are three different modes for estimating the trace zero lines, and the mode can be selected in the **Trace Identification Method**(☣) box. The default **trace** method[7] looks at the objects classified as trace objects and then fits trace-zero lines to their locations. The **trace mask** method considers trace object pixels to be the only valid pixels of the original image and ignores the rest. The **image** mode is the least accurate and looks only at the image itself without taking any of the classification data into account.

The **Adjust Traces** button will only populate after the Trace Identification algorithm has been run[8], and can be used to manually adjust the number of traces, and their locations.

[7]This has consistently been the most accurate method in testing, and there are very few cases where this would not be the case, so long as the trace objects have been properly defined in the Edit Classification step.

[8]This is done by pressing the associated left sidebar button back in the Main DigitSeis Window.

Figure B.3: Shown above at left is the + menu brought up by clicking the button to the left of the **Identify Traces** button. Clicking the **Adjust Traces** button in this menu will bring up the spreadsheet-type display shown above at right. Here the user can add, delete, or move trace-zero lines.

Pressing the **Adjust Traces** button will bring up a spreadsheet (**Figure 5.3**) with the trace-zero lines organized in rows. To move individual traces, the user can modify the **First y-pixel**, **First x-pixel**, and **Last x-pixel** parameters. To remove a trace, the user should simply uncheck the box under the **Active** column corresponding to that trace and click the **Apply** button. To add a trace the user should use the + button in the bottom right corner. Clicking this button will take the user back to the main DigitSeis window where they will have to click the starting position for the trace they are adding. This will bring up a circle that the user can drag to the point they would like to define as the start position of the new trace. Once the start position is finalized, double clicking anywhere will confirm this selection and a new

zero-line will be added. Finally, in the case where all trace zero-lines seem to be offset either too far above or below the traces they correspond to the user can move all traces by a given offset using the ˆ button to the left of the + button. This option asks the user for a vertical offset in pixels to move all trace zero lines by[9]. The **Apply** button can be used at anytime to update trace-zero lines to reflect the changes made. Once the user is satisfied with the changes, they simply close the window.

[9]Note that y values increase downward, so a positive value will lower the lines.

B.3 Digitize

Figure B.4: + Menu for Digitize

The Digitize + menu hosts parameters that allow the user to control how far of an area to either side[10] of the trace zero lines the Digitization algorithm looks for objects in. These are the boxes in the top left of the window.

Below these parameter boxes are the **Check Traces** and **Check STD** tools. These allow the user to highlight a given trace number[11]. If no trace number is specified, pressing either button will cycle through all the traces (this is especially helpful for checking that traces are in the right order).

In cases where traces are not in the correct order, they can be added, deleted, or reassigned using the grouping of three buttons found just below the **Check Traces** and **Check STD** buttons. Again, the box next to the **Delete Trace** button is used to specify a trace by number.[12]

The user can also uncheck the box at bottom of the window if they would like to see a pie-chart progress display as traces digitize instead of the current traces (if any) being removed and new ones drawn as they are calculated.

[10] In this case "either side" is meant to mean above and below rather than to the left and right of.

[11] This number corresponds to that of the trace numbers that were assigned and labelled in the Trace Identification step, and should be input into the box next to the **Check ...** button.

[12] Note that if there are many problems with traces and their order, it is often easier to re-run the digitization, or even go back and re-identify traces. If it is the case that the traces are not being identified properly, there may be issues with the Classification.

B.4 Correct Trace

Figure B.5: + Menu for Correct Trace

The first parameter in the Correct Trace + menu is similar to the **Image threshold (%)** parameter in the Edit Classification + menu (**Appendix B.1**), just applied to the classification calculation done in the Correct Trace window[13].

The next two groupings are to control the intial size of the **Box for Trace Selection** and the **Correct Trace Window Selection**. The **Box for Trace Selection** is the starting size of the box that the user uses to select the area they would like to correct as is described in **Section 6.2.1** and shown in **Figure 6.3**. The bounds here are measured in pixels relative to where the user clicked on the trace. The **Correct Trace Window Selection** refers to the separate window which is brought up after selecting the region to correct. The bounds here are in normalized units and these settings are analogous to the **Small Classification Window Setup** group of parameters in the + menu for Edit Classification (**Appendix B.1**).

The next drop-down menu titled **Interpolation Scheme** refers to the method used by the point fitting tool (**Appendix C.3** and **Appendix A.4**) to connect the points (linear or spline)[14].

The **HRV Hour Mark Identification** tool will identify and highlight the double-timemarks used as hour markers in the early HRV (Harvard Seismic Station) records[15]. It then recalculates the digitized trace around the second of the double-timemarks, this corrects slightly different vertical offsets between the hour marks.

If the check box marked "full image when switching to classification" is checked, the program will snap back to the whole area being corrected (any zoom will be lost) when toggling between the underlying image and the classified objects in the Correct Trace Window.

In rare cases, DigitSeis may become very slow during trace correction. If this is the case, the **Reset Window** will save where the user currently is, and then close and reopen the program clearing the memory logs of unneeded data.

[13]Note, again that there is a also a way to change this parameter within the Correct Trace window in the form of the box and red button at top right.

[14]Linear interpolation may be needed for traces that have very rapid motion creating linear "zig-zag" traces.

[15]This is fairly specific to HRV records, but can probably be used on most seismograms that use the "double timemark" to mark the hour.

B.5 Calculate Timing

Figure B.6: + Menu for Timing

In the Calculate Timing + menu, the user can reset the default reference time in the **Reference Time** group of parameters[16]. The user can also reset the increment at which the absolute time is displayed using the **time display increment** parameter. The default value of 15 for this parameter, gives the "15-minute marks" described in **Section 7.2** and shown in **Figure 7.3**.

While the parameters described above are mostly for convenience and appearance, the next group of three checkboxes is very important for timing accuracy and can be seismogram-dependent[17]. The first of these is the **time on left** setting, which will put the beginning of the absolute minute on the left-side of the time-mark[18]. The **ignore timemark** parameter will calculate time based solely on the reference times provided and their corresponding trace length[19]. The third checkbox labelled **use trace gap to time** will treat gaps in traces as timemarks, and this option should be used if the timemarks in the seismogram being digitized are gaps in the trace (as opposed to offset segments).

The **Segment Trace** button allows the user to deal with time discontinuities within a trace, and will allow the user to time multiple portions of the same trace independently of one another. This is done by right-clicking on one of the purple vertical bars generated in the main DigitSeis window and selecting **Segment Trace**, the tool is exited by right-clicking anywhere. Where the trace was segmented, marks the divisions between what are now essentially separate timings. The **Reset Time Info** button allows the user to remove all current timing data and recalculate the timing from scratch, something that is often helpful when mistakes in setting reference times lead to messy timing extrapolations.

Finally, the last parameter box marked **factor for vertical time bar length** will control how the timebars appear.

[16]The default reference time is the date initially displayed in the **Set Reference Time** box shown in **Figure 7.2**.

[17]Some of the information that would affect these settings may have to be sourced from the original station logs.

[18]The default for this parameter, and the convention at the HRV station is for the minute to begin on right side of the timemark.

[19]This method is much less accurate than using timemarks for reference, and should only be used in cases where there are no timemarks present or those timemarks have been deemed to be unreliable.

B.6 Extract SAC

Figure B.7: + Menu for Extract SAC

The Extract SAC + menu allows the user to control the sampling of and time-correction applied to the SAC files. This is done using the **SAC Interpolation** parameters and the **Time Correction (s)**[20] parameter. The SAC files are generated with the Interpolation Sampling rate specified here by the user. Note that the user can also uncheck the **time to nearest second**(☣) box, however, this is not recommended.

The user can also deal with complicated or non-linear trace-zero lines with the tools in the **Additional Zero Line Correction** to apply a higher-order polynomial fit to the trace-zero-line calculation. However, note that this higher-order polynomial fit is not used for time assignment when there are no timemarks (for those with timemarks, the trace trace-zero curve has limited implications).

The third grouping of parameters (**Station/Record Information**) sets the default values for information that gets input into the SAC headers. Note that these parameters just set the initial values that can then be changed in the **Extract SAC** window as shown in **Figure 8.1**. Note also, that if the user desires a blank **Extract SAC** window, then the **Station/Record Information** defaults can be set as empty and saved.

[20]This particular parameter does not save for all subsequent analyses and is instead analysis specific

Appendix C

Dealing with Crossed Traces

The main body of this manual[1] deals with how to do a "simple" digitization with well-separated timemarks[2] and more importantly, no crossed traces. Crossed traces occur when the amplitude of a trace (for example, if an earthquake were to occur) exceeds the spacing between them, this causes the traces to "cross" over one another as shown in **Figure C.1**. This part of the manual provides some hints and methods for dealing with this type of problem. Note however, that these are methodologies found useful and efficient by the author, not necessarily the most efficient and useful way. That being said, the user should approach this as a starting point from which they can modify as they see fit to develop their own strategies for dealing with these more complicated analyses.

Figure C.1: This seismogram depicts the arrival of a teleseismic event whose amplitude is greater than the spacing between traces, leading to a "crossed trace" situation.

[1] **Chapter 1** through **Chapter 8**.

[2] At times, the timemarks are offset but not fully separated from the trace. They are therefore classified as being part of the trace and must be manually separated in the Edit Classification step.

C.1 Classification of Crossed Traces

Figure C.2: In the above image, two main problems can be observed (1) there are several crossed traces (2) because the crossing trace is "stretched" it is not as visible, and some data appears to be missing.

When a situation as shown in **Figure C.2** is left as-is, there will be a problem when traces-zero lines are calculated, and consequently, also when the analysis is digitized. The problem here is that due to the crossing trace having amplitude that causes it to overlap with other crossed traces[3], they are classified as one object. This large object spanning multiple traces creates problems for both the trace-zero line calculation and the digitization algorithm, since both function by assigning each object to a single trace.

[3]From this point forward the trace whose large amplitude causes it to overlap with other traces will be referred to as the "crossing trace", while the traces which the "crossing trace" overlaps will be referred to as the "crossed traces".

Consequently, the general solution to a crossed trace situation is to separate the crossed traces from the crossing trace so each can be an individual object which will be properly assigned to the trace-zero line that it belongs to. The way that the author prefers to do this[4] is to separate out all of the crossed traces as coherent objects in the classification stage and leaving the crossing trace cut up to be recovered in the Correct Trace stage. The way this would be classified is illustrated in **Figure C.3**. This approach also avoids the potential for objets belonging to the crossing trace to be identified as part of one of the crossed traces.

Figure C.3: Separation of crossed traces by cutting the crossing trace.

Note that from this stage, the user could proceed to the trace zero-line calculation and digitization, and then can recover the crossing trace using the Correct Trace function (the method that will be detailed in this appendix). Alternatively, at this point, the user could also define pixels belonging to multiple objects using the **Overlapping Trace Tool**, and combine these with their respective traces using the **Combine Objects Tool**. For example, see **Figure C.5**.

[4]Note again, that this appendix should serve as an example of *one* way in which this can be done. DigitSeis is an extremely versatile program which, once proficient, a user can utilize in numerous ways to take care of such complicated situations.

Figure C.4: Shown here is an object that is really two separate objects with significant overlapping portions.

Figure C.5: Using the **Retrieve Original Image** tool (second from left), the overlapping region has been defined here and as a result has turned pink, and the surrounding objects reclassified.

Figure C.6: The pink overlapping region can be assigned to multiple objects, and so the three components each of both the top and bottom trace (including the overlapping region which is common to both) are combined with the **Combine Object** tool and the modification applied.

C.2 Correction of Digitized Crossed Traces

Figure C.7: Shown here is the result of digitizing the classified crossed trace situation shown in **Figure C.3**. Note how the crossed traces are intact and properly digitized, while the crossing trace needs correction.

After the traces have been digitized, it can be seen that the crossed traces look to be intact and properly digitized. However, because it was left in a cut-up state in the Edit Classification stage, the crossing trace is not properly digitized[5]. This can be remedied by using the **Correct Trace** tool to re-classify and redigitize the crossing trace. As described in **Chapter 6**, and shown here in **Figure C.8**, the trace of interest (in this case, the crossing trace) is isolated by removing the other sections of the base image and then classified. This new classification is then digitized and reapplied to the original image, resulting in having correct digital traces for both the crossing and crossed traces (**Figure C.8**).

Figure C.8: In the upper part of the image, the un-isolated trace can be seen in the base image, and in the lower part, the crossing trace has been isolated and classified.

[5]This is easily seen since there are several gaps where there are no digitized traces (blue lines) over the trace. The gaps can be emphasized by using the **Find Gaps** tool (**Section 6.2**).

Figure C.9: The new classification is then used to recalculate the digital lines for the trace as shown in the upper portion of the image. These new digital lines are then merged back into the main analysis to give the correct classification (lower portion).

C.3 Point-Fitting Option

At several points throughout this manual, the **Point Fitting** option in the Correct Trace window has been mentioned. This tool provides a way to create objects without having to deal with removing regions from and generally modifying the base image. This is especially helpful in cases where the traces on the base image may be very light, or where there are enough crossings that it would be easier to fit a curve to the crossing trace than isolate it from many crossed traces.

To use this tool, simply click it in the Correct Trace Toolbar (**Appendix A.4**) and then select points along the trace which you would like to create an object for[6]. Right-click when the points have been picked, and a red line will be fit to the points that were selected[7]. The points are movable by clicking and dragging, and should be adjusted until the red line overlays the trace with reasonable precision. An example of this process is shown in **Figure C.10**. If the trace is rapidly undulating, the spline interpolation may be too smooth to reproduce the line. In this case, change the interpolation scheme to linear (**Appendix B.4**).

[6] A set of yellow crosshairs will appear when you are in this point picking mode

[7] The end points from this first picking of points will represent the endpoints of this object. Points added between these end points will be incorporated into that object. If a new object is desired, add points outside of these original endpoints. If the objects are overlapping, create the second object and then move the endpoint after the object has been defined.

Figure C.10: Shown above is the base image with the point selection in blue and the fitted curve in red.

Figure C.11: Shown here is the object generated by creating object pixels around the fitted line shown in **Figure C.10**.

Once the user is satisfied with the line[8] that has been fitted, the **Point Object Generation** tool[9] should be used to generate objects from the lines which have been fitted (**Figure C.11**). These should be classified in the normal way and should from this point forward be treated the same as if they were objects that had been created by brightness analysis of the original image[10], and can be simply digitized (**Figure C.12**) and merged back with the main analysis.

[8] Or lines, in the case of multiple objects.

[9] To the right side of the **Point Fitting** tool in the Correct Trace Toolbar (**Appendix A.4**).

[10] That is, the standard method that has been used throughout this manual.

Figure C.12: Shown here is the digitization of the object shown in **Figure C.11**.