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Digital Dissection of Radiographs, Using the Early Cretaceous Bird Confuciusornis and Photoshop CS2TM

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Digital Dissection of Radiographs, Using the Early Cretaceous Bird *Confuciusornis* and Photoshop CS2™

A Thesis

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ABSTRACT

DIGITAL DISSECTION OF RADIOGRAPHS, USING THE EARLY CRETACEOUS BIRD *CONFUCIUSORNIS* AND PHOTOSHOP CS2^{TM}

By

Sirelious White

In the past, radiographs (x-ray "shadowgraphs") have been used by paleontologists as ways to identify and capture bone images. Primarily, this was done to examine the skeletal elements without having to remove the surrounding matrix. Radiographs have so much three-dimensional information compressed onto a two-dimension image that it is often impossible to understand the entire skeleton. Obviously, it would be desirable to strip away the readily interpretable skeleton elements and examine those less well understood.

An initial set of experiments were performed on a particular section of a radiograph of *Confuciusornis sanctus*, as a subject, while utilizing Photoshop CS2^{TM} to perform a digital dissection. The technique was successful enough to save and remove bones from the image, leaving a white image in its place. Although the project was limited by some inherent corrections within Photoshop, the writer is able to demonstrate the feasibility and future potential of the process.

INTRODUCTION

The purpose of this project is to explore and develop a novel methodology for radiographic interpretation. The primary problem is that radiographs contain large amounts of overlapping information, which is far more complex than the surface information that a human brain is accustomed to processing. While some information within such a complex image may easily be interpreted, much information is lost in the confusion. Obviously, it would desirable to completely remove the understandable images, so that the confused portions can be interpreted. This general approach is herein coined "radiograph dissection".

While this approach will work with any radiograph image, it is here tested on a vertebrate fossil, primarily because the individual bones allow for easy definition of the images to be removed. Basically, the sample radiograph will be dissected, one bone at a time (Figure 1). In order to dissect a radiograph, the understood information to be removed must be isolated, saved, and then removed from the image by using the saved portion of the image, inverting the pixel values and adding this file to the original image. In effect, this will cancel out the portion which was interpretable. If performed properly, this inversion-plus-addition will leave only the underlying images, exposing them for subsequent interpretation. If understandable bone is adequately defined, there should be no trace (or "ghost") of it on the dissected image. This provides a partial methodology for checking the quality of each interpretation. Any inversion-plus-addition that leaves a ghost is imperfect and must be completely redone. Conversely, any time that the dissected bone has a ghost of another bone, the bone must be redefined and the operation redone.

Another purpose of the project is to introduce Photoshop CS2^{TM} as an easy to use vertebrate paleontology tool that can be used to manipulate and interpret digitized radiographs to assist in the preparation of fossils. The proposed technique utilizes a radiograph of *Confuciusornis sanctus* as a subject. This process involves a series of steps that are not automated at this time.

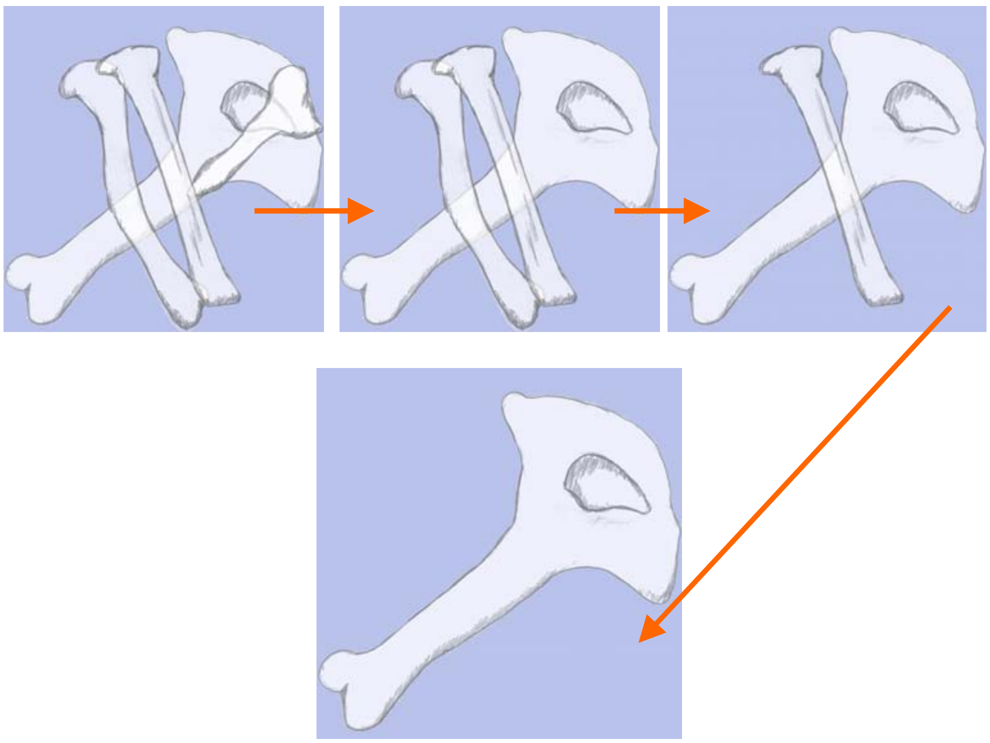

Figure 1. Shows the concept of removing information from the radiograph. Each bone is isolated, saved and then removed one by one, leaving wanted information behind for later study.

The fossil is one of several specimens of *Confuciusornis sanctus* housed at the University of New Orleans. *C. sanctus* is an ancient bird found in the Lower Cretaceous Yixian Formation of Liaoning, China. Details of the occurrence are recorded by the American Museum of Natural History (Chiappe and others, 1999: 5-8).

The subject is embedded within a shale matrix with major portions of the fossil exposed (Figure 2). Some bones are damaged, a few are completely missing (as shown by their impressions on the slab or rock), and a few are completely hidden within the matrix. The fossil was X-rayed by K. Derstler in 2002 and this radiograph, plus the actual fossil, was used for the work reported herein.

Figure 2. Fossil of *Confuciusornis sanctus* currently housed at University of New Orleans.

Radiographs have a long history of use in paleontology. Brühl experimented with pyritized Hunsrück Slate fossils in 1896, only nine months after x-rays were discovered by Wilhelm Röentgen. Most recently, these same kinds of fossils were studied by Lehmann using refined X-ray techniques to study structures that were invisible at the surface. "He produced more than 90% of the 170 radiographs of Hunsrück Slate fossils published by the time of his death in 1959." (Bartels and others, 1998: 263-264). Other examples of radiography in paleontology can be found in Stürmer, Branco, Jackel and Mauz (Hohenstein, 2004: 420-425). In each case, the fossils were interpreted visually as a total image. Here, we attempted to improve the interpretation by first digitizing the radiograph and then dissecting it, bone by bone.

The software used is Adobe Photoshop CS2™, which is commercially available and affordable. It is among the most recognized programs for manipulating digital images. Extensive research was done to see if this method was already implemented with Photoshop and could not be found. Photoshop CS2™ was chosen for its price, expandability through plug-ins, automation tools, graphical interface, ease of use, and organization within its file format. The software can handle very large files and various file formats, making it a very versatile package. It is also compatible with a host of other Adobe products, which makes publishing or sharing work quick and easy.

The remainder of this paper will discuss the methodology used to accomplish the goals of the technique.

MATERIALS AND METHODS

The subject fossil was x-rayed, using a Faxitron radiograph machine. The resultant image was recorded on single-sided Kodak Medical X-ray Films and machine setting of 50 kilovolts and 5 milliamps (personal comm., K. Derstler 2006). The resultant radiographs were scanned on a large format UMAX Mirage D-16L scanner. The resulting non-compressed TIFF images retained a resolution of 800 dpi, 8-bits per channel color depth in RGB, and created file sizes of roughly 146 megabytes each. Only one of the three actual scanned images was used. In fact, this image was cropped to a small target area within the original radiograph (Figures 3–6). The target area includes the right-side humerus, coracoid, scapula, furcula, radius, radiale, metacarpals, ulna, phalanx, digits, various ribs and vertebrae. By cropping the radiograph, access speeds were much faster and reduced the chances of corrupting the file during incremental saves. All mentions of fossils, bones, radiographs, etc. are herein referring to the digitized image, cropped radiograph (CR) and not the actual fossil unless otherwise explicitly expressed.

Figure 3. Radiograph of upper portion frontal view of *Confuciusornis sanctus*.

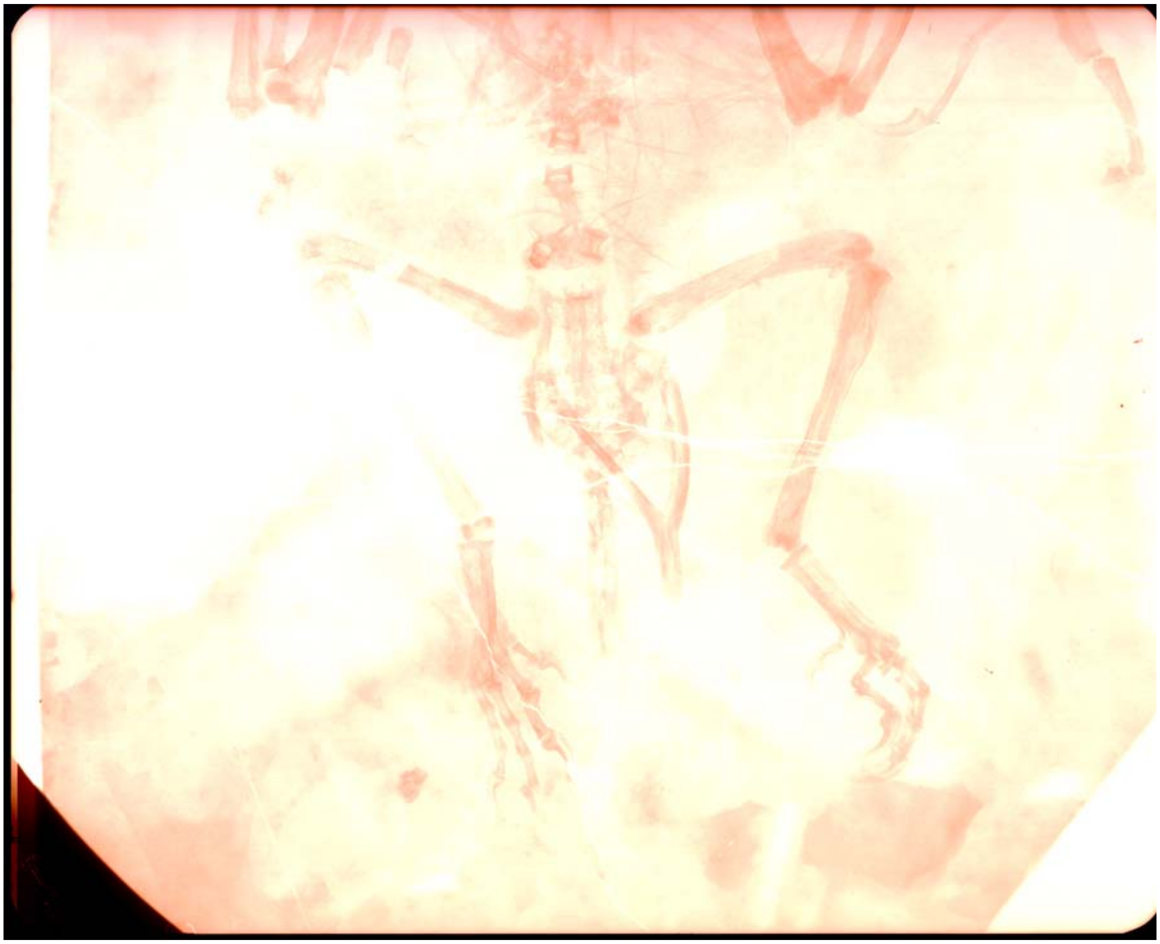

Figure 4. Radiograph of lower portion frontal view of *Confuciusornis sanctus.*

Figure 5. Radiograph of profile view of a second specimen, *Confuciusornis sanctus.*

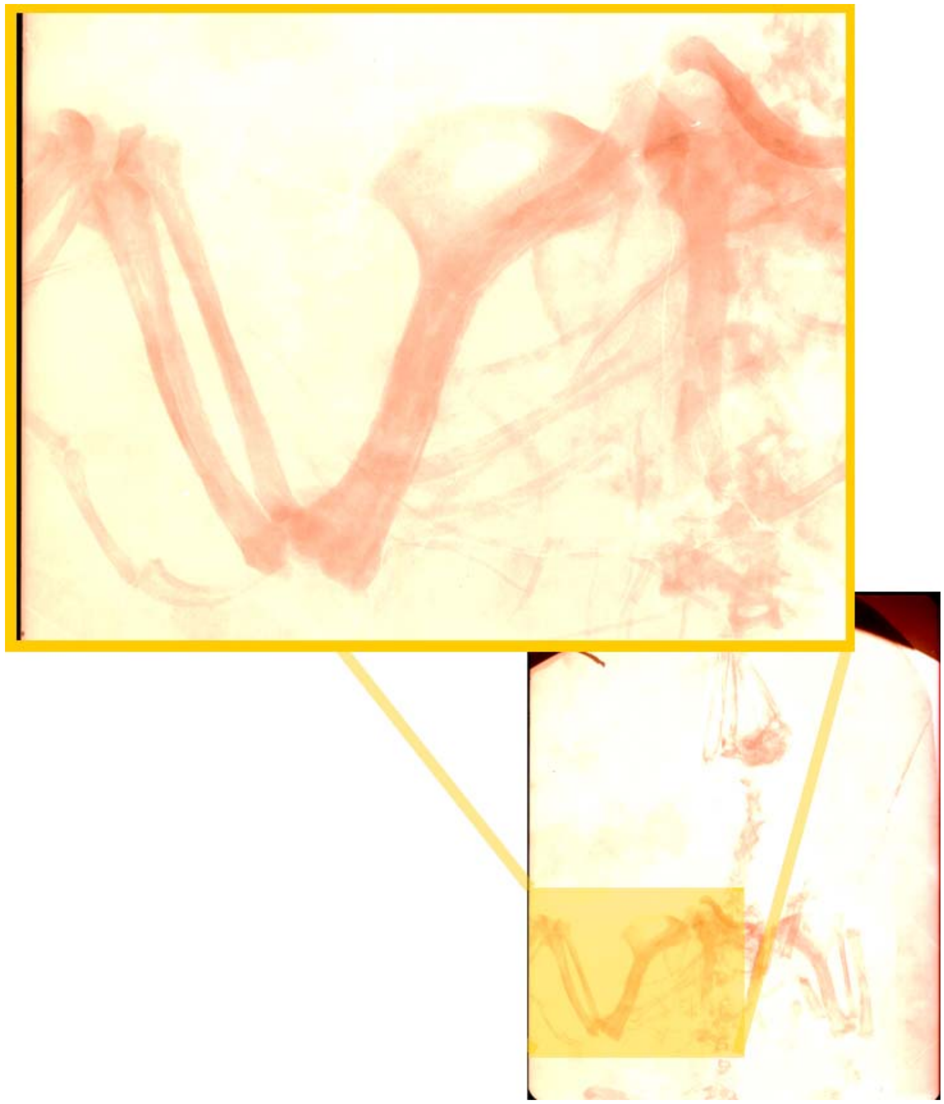

Figure 6. Cropped area of the upper frontal view radiograph for use within the technique.

Once the digitized radiograph was available, the writer conducted preliminary experiments to see how Photoshop CS2 would perform various calculations on images. There are several blending modes that can be used to combine two images together within Photoshop (PS). As it turned out, the result of the subtraction (because of the use of a numerically inverted image) revealed that it can not be directly used because its computational algorithm compensates for pixel values that the software judges to be too light or dark. The addition calculation works well and does not compensate for light or dark pixel values, unless the values are less than 0 after an addition or greater than 255. In this case, it clips the values at 0 or 255 respectively. See the Appendix A for more details.

After determining the limits of the Photoshop CS2 algorithm, the writer imported the cropped radiograph (CR) into PS. Here, several colored and filtered variations of the image were created (Figure 7a-d). PS creates a grayscale image (only various shades of gray) as a resultant of a calculation, so the main interaction was with grayscale images. The variations assisted in interpreting between the bones and the rock matrix. Some of the variations includes, the original color image, a highly saturated blue monochromatic image for easier viewing of the varying density changes, a high pass filtered image with use of a linear light blend mode, embossed and glowing edges to make use of the distinct boundaries that are created to border each bone. The sternum, for example, is faintly visible due to the sharpening of the image, whereas without sharpening, it would be indistinguishable. Each variation was within its own layer within the PS file, which would allow overlapping the other layers with their opacity reduced to compare details from one image to another.

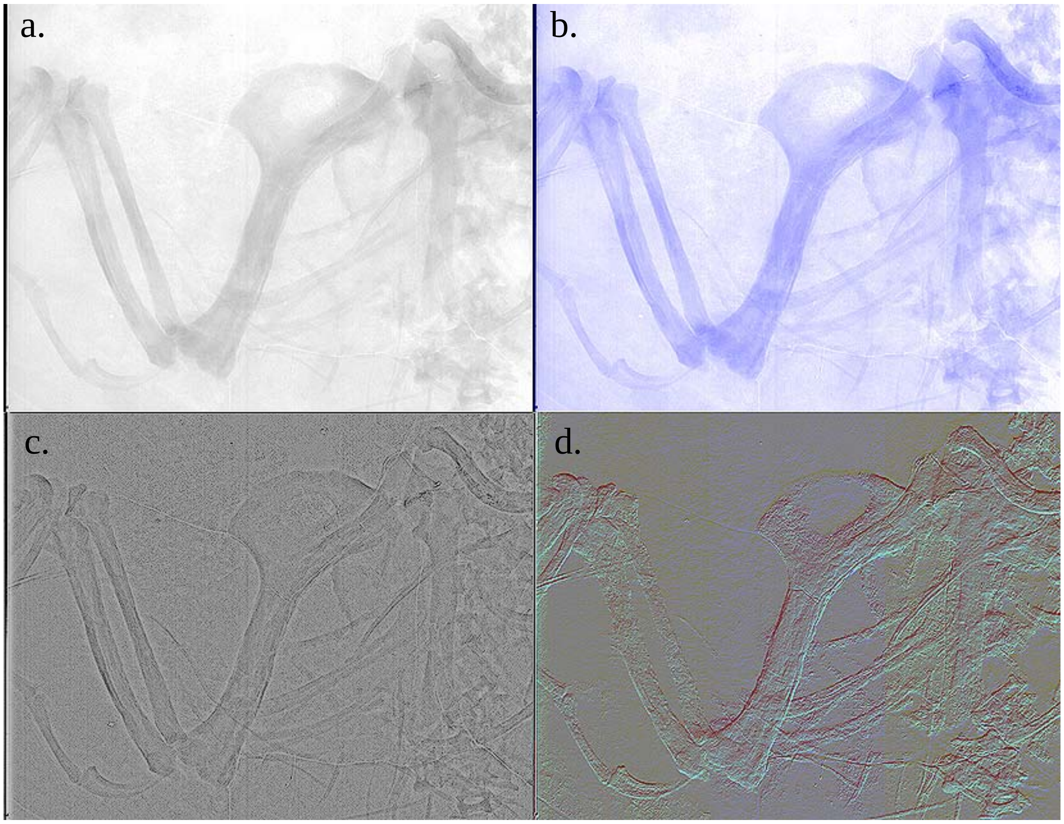

Figure 7a-d. a. shows the original color radiograph transformed into a grayscale image. b. shows a blue monochromatic variation for easier viewing. c. shows the result of a high pass filter used for sharpening the image. d. shows an embossed version of the image to help detect the edges of the bone.

Once the variations are created, the process begins with the identification and interpretation of the bones. The actual fossil, as well as published material (Chiappe and others, 1999: 10-79), and other fossils of the same species were used as a guide to interpret the radiograph image of each bone. The lasso tool within PS was chosen to outline the shape of the targeted bones, while a Wacom CTE-630 digitization tablet was used to assist in the outlining of the bones due to its pen-like mouse and natural pointer movement. Note that the interpretation is not automated; rather it is largely dependent on the operator's ability to distinguish bone edges in the radiograph. In short, this is a tool to assist the paleontologist's interpretation, not a substitute for human interpretation.

The first bone chosen to interpret was the humerus, because there were several bone structures overlapping it within the image. The whole shape of the humerus, despite any overlap, was outlined and then saved as a path. A path is a vector shape consisting of points connected with lines within the PS file. If the path, which starts off as a work path, is not saved, then the work path will always be the current selection and can not be recalled later.

The bones that overlap the humerus were also outlined separately (coracoid, radius, and rib material), including any areas where they overlapped the humerus, then saved as paths (Figure 8). Each path was given the name of the bone for easy identification later and every bone that could be identified within the CR was given its own path as well. It was also important to switch between the CR variations in order to have more accuracy when selecting the outlines of the bones.

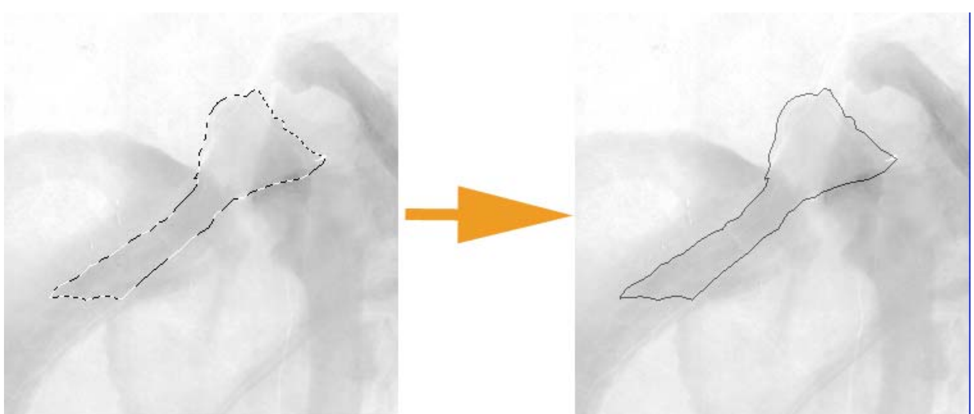

Figure 8. Changing a selected outline of the coracoid to a path to be saved.

Once all of the paths were created, each was used to create a selection of the identified bone, copied from the grayscaled image, and pasted into a new layer so that the bone would become isolated within its own layer. Photoshop allows for the grouping of layers within the PS file, so all of these new layers were placed into a group called "Defined Bones".

The first steps of extracting the humerus, for example, were to duplicate the isolated layer of the humerus so that two layers exist, with an alpha channel as a background. An alpha channel basically represents a clear or invisible set of pixel values within an image. A duplicate of the original CR grayscale layer was also created and selected. Next, the path for the humerus was selected using the Control key, which converts it to a selection. To select the intersection of the overlapping bones, the Control, Shift, and Alternate keys were held down simultaneously and each of the paths of the overlapping bones were then selected as well. This combination of steps created a selection around only bones overlapping the humerus.

To paint the overlapping intersections, the paint bucket was selected, and the gray foreground value of 255 (pure white) was chosen as a fill color. The duplicate layer of the isolated humerus was chosen and the intersection was then filled in with the fill color of 255. Once this was done, the humerus could be subtracted from the image.

The addition calculation feature allows for two layers to be added to one another. The inversion of a layer can also be performed during this process. In this case, the source image, being the duplicate of the CR grayscale layer, was added to the inverted isolated humerus layer with the painted intersection. This process performs a subtraction of the humerus from the duplicate of the CR grayscale layer and creates a new document which can be added to the current document to be used as the new source layer if a series of bones are to be subtracted from the image in iterations.

The technique was created and implemented on an IBM compatible computer equipped with an AMD 64 X2 dual core processor 4400+, dual NVIDIA SLI graphics cards with 128 MB of RAM each, 2 Gigabytes of RAM and over 500 Gigabytes of hard drive space, running Windows XP professional.

RESULTS

The technique described above has proven useful, if limited, within the Photoshop CS2 environment. The resulting image shows the removal of the humerus so that the rest of the image could be interpreted thereafter. The original hopes were to remove a layer of the image and leave any portion than can be seen below to remain intact and within the image. For instance, if two bones overlap, such that we can see the underlying bone, we can remove the upper bone and the lower bone would remain without a trace or ghost of the upper bone in the image. A white space is left behind when the technique is used, which appears as the shape of the removed bone (Figure 9). Any overlapping bones must be outlined separately and their intersection painted so that they will still show after the addition calculation has been done. A series of removed bones are in Appendix B.

Figure 9. Removal of the humerus leaves behind a white space and overlapping portions of the image.

Using a value of 255 to paint overlapping bones will yield the same pixel values of the overlapping section before the calculation function has been applied. This is because 255, when inverted, becomes 0. Adding 0 to the current images yields no change in the image. Unfortunately, due to the added density of the overlap, the overlapping portion of the bone will look darker than the rest of that particular bone, where no overlap occurs. To rectify the situation, with the overlap selected, the selection can be adjusted for brightness and contrast. A better way to correct this may be to take a sample of the existing color value before using the calculation function; we'll call it Sample A. Next, take a sample of the color value of the portion of the bone that does not overlap, we'll call that Sample B, and use the following equation to find a gray to paint the overlapping sections with the following equation:

$$255 - (B - (255 - A)) = \text{Painted value.}$$

For bones that are not overlapping one another, it is found to be faster to select the bone outline and fill the area with a value of 255 to erase it from the image. This cannot be done easily with overlapping sections and the technique must be implemented in the case of an overlap.

Photoshop gives the interpreter the ability to save portions of the image that were removed for later retrieval and manipulation within the same file. It also allows for the naming of each bone outline and to place them into a folder within the file for better organization. The "root directory" of the file, in this procedure, contains the copies of the original image along with the manipulated images. The images with each bone extraction during the process were placed into a folder called “x-tractions”. The bones that were pulled out of the image were placed within their own folder as well, called “colored bones”. Another folder was created for the grayscale bones. All folders were maintained within the Photoshop formatted file (.PSD). Paths were also saved within the file, which can be converted into selections anytime they need to be recalled.

Once the technique has been administered a couple of times, it becomes quicker to implement. The process of removing the humerus took approximately 10 minutes after all the bones were outlined and saved as paths, but it should be known that I have prior experience as a graphic specialist and have repeated the process over many instances. The use of the Wacom digitization tablet will also help improve the speed of the process. An optical or traditional roller ball mouse has trouble with interpreting natural hand movements. They require zooming into an area many times in order to gain accuracy over a small area of pixels.

Photoshop is a valuable tool for vertebrate paleontology interpretation. Added suggestions for taking advantage of the Photoshop file format are within the Appendix C.

DISCUSSION

Benefits:

While the methodology explored herein is limited by the automated adjustments made by Photoshop CS2, the technique is obviously useful to paleontologists who wish to interpret their radiographs quicker and more efficiently. Within Photoshop, it is easy to store interpretations, make notes, and place graphic markers on digital samples to be prepared. This technique will definitely help paleontologist interpret radiographs quicker and more efficiently. With Photoshop, it is easy to store interpretations, make notes, and place graphic markers on digital samples to be prepared. Samples that are not fully exposed from their rock matrix will be easier to distinguish where buried portions of the fossil lie, making it easy to map out sections to prepare. By first checking the radiograph, adjusting the scale of the image, and interpreting, the process of preparing a fossil will be safer and faster. This process will also assist in the documentation of each bone that is to be removed from the sample if documentation is necessary.

Radiographs:

The quality of the radiograph can make a huge difference in the interpretation process. There were portions of the radiograph that were indistinguishable, making it hard to make a definite decision on the outline of certain bones. This was most notably found in the outlining of the scapula. Density contrasts were not strong enough to distinguish its border and that of overlying bones. The quality of the digital radiograph could also be due to artifacts created by the scanner settings during the scan phase.

Software:

Software will have to be created to achieve the removal of a bone without removing the background information, such as underlying bones and other artifacts below the bone image. At this time, the current technology only allows for leaving a white background image. It is also desirable to make the technique automatic within the software. For instance, a paleontologist should be able to outline the bone he wishes to remove and click one button to have it removed. If a ghost of the image is still there, he should be able to undo the previous results and try again with a different set of parameters. Photoshop has a Software Development Kit (SDK), which lends itself well to creating automated tools to perform a series of repeatable tasks. The program also has built in automation functionality that the user can activate by assigning a hot-key. A list of other graphic software that may be capable of producing the same results are listed in Appendix D.

Interpretation:

It is probably best to use all available sources of information during the interpretation of the radiographs. For this project, observations directly on the fossil, as well as comparison with other specimens of the same species, as well as radiographs, mosaics, sketches of other workers' interpretations, published images of the species' osteology (Chiappe, 1999: 10-79) and many filtered versions of the radiograph was used during the interpretation phase.

There are many other sources that could have been utilized if available, such as higher quality x-rays or better scans, fluorescent photographs, stereo pair images placed on a light table using a stereo viewer, and a video microscope. Imported images that are scaled to the scale of the radiograph and positioned correctly can be layered over the radiograph image.

Further work:

The next phase, as mentioned above, is to make the process more automated with a customized user interface. Naturally, this automation will not include the actual interpretations or paintings, but only the manipulation and storage of the data. The Photoshop SDK utilizes the power of C++ and C# to create plug-in modules to manipulate the images or automate features. By automating the process, it will make implementing the technique faster. It will also reduce the need to have a multiple layers for the extracted bones, intersections, paths, and isolated bones, thus reducing the size of the Photoshop file.

Once this technique and use of Photoshop is accepted widely within the paleontology community, a communication system will be needed as well as a set of standards for organization and marking digital radiographs. I imagine a system similar to what is used in the medical community for sending x-rays, along with its attached metadata, from one medical center to another. Their system is called PACS. For more information, see Appendix E.

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APPENDICES

APPENDIX A

First Experiments in Photoshop

The first experiments in Photoshop were performed in order to recognize the capabilities of the software, even before using radiographs. It is the desire of the writer to understand as much as he can about the algorithms used within the program. The following experiments and tests were performed to push the limits of the software and functionality.

Experiment #1

Two test patterns were created to examine the pixel blending functionality within Photoshop. The test patterns are shown below in Figure A1-1. Three layers exist within the test file. One with a four square test pattern (4SP), another is the same with two squares in the middle (6 square pattern or 6SP), and a third layer of solid gray of value 126. Combining the two first patterns can yield up to 12 different color values at once (zones).

The objective was to find a way to adjust the amount of opacity so that when the objects were subtracted, we can understand the algorithm enough so that the output values can be controlled.

Test 1, Difference Blend:

This test will use the difference image calculation on the second layer and the first layer being the four square pattern. The Opacity Fill setting will be incremented from 0% to 100% by a value of ten per iteration. Figure A1-2 and Table A1-1 displays the results.

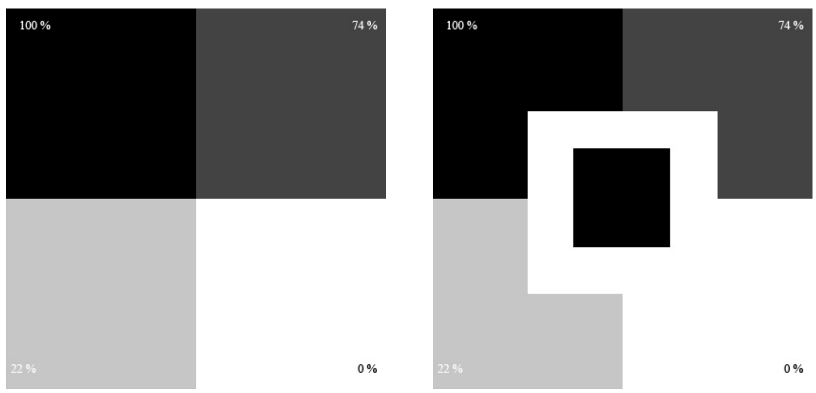


Figure A1-1. Test patterns used to measure pixel values after combining them with various blending modes.

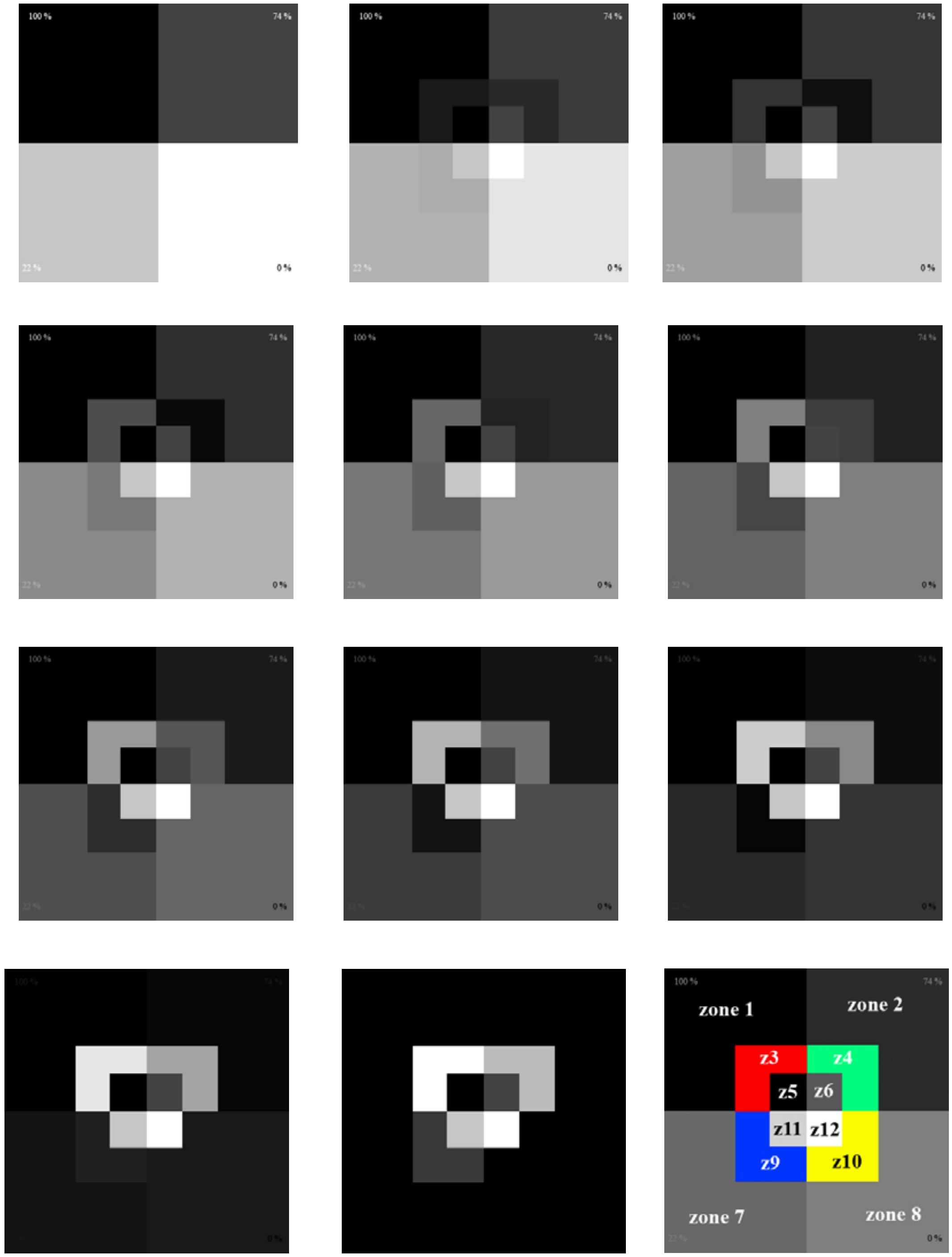


Figure A1-2. Results of the test as the opacity fill is adjusted from 0% to 100% from top-left to bottom-right. Zone identification is shown in the last image.

The following table illustrates the results (K%, RGB):

O-Fill %	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12
4SP	100, 0	74, 88	100, 0	74, 88	100, 0	74, 88	22, 210	0, 255	22, 210	0, 255	22, 210	0, 255
6SP	100, 0	74, 88	0, 255	0, 255	100, 0	100, 0	22, 210	0, 255	0, 255	0, 255	100, 0	100, 0
0	100, 0	74, 88	100, 0	74, 88	100, 0	74, 88	22, 210	0, 255	22, 210	0, 255	22, 210	0, 255
10	100, 0	76, 80	90, 37	84, 58	100, 0	74, 88	30, 193	10, 235	33, 188	10, 235	22, 210	0, 255
20	100, 0	79, 73	80, 70	94, 22	100, 0	74, 88	38, 176	20, 215	42, 166	20, 215	22, 210	0, 255
30	100, 0	82, 65	70, 99	96, 12	100, 0	74, 88	46, 158	30, 193	53, 143	30, 193	22, 210	0, 255
40	100, 0	84, 56	60, 124	86, 50	100, 0	74, 88	53, 141	40, 172	62, 118	40, 172	22, 210	0, 255
50	100, 0	87, 47	50, 149	76, 81	100, 0	74, 88	61, 122	50, 148	73, 91	50, 148	22, 210	0, 255
60	100, 0	89, 39	40, 172	66, 108	100, 0	74, 88	69, 101	60, 124	82, 63	60, 124	22, 210	0, 255
70	100, 0	92, 28	30, 194	56, 134	100, 0	74, 88	77, 79	70, 98	93, 27	70, 98	22, 210	0, 255
80	100, 0	95, 17	20, 215	46, 157	100, 0	74, 88	84, 56	80, 70	98, 5	80, 70	22, 210	0, 255
90	100, 0	97, 6	10, 236	36, 180	100, 0	74, 88	93, 27	90, 36	87, 46	90, 36	22, 210	0, 255
100	100, 0	100, 0	0, 255	26, 202	100, 0	74, 88	100, 0	100, 0	78, 77	100, 0	22, 210	0, 255

Table A1-1. The table shows the luminosity, K, and the value for each shade of grey produced. When all RGB values are the same, they create a grayscale image. When a difference blend is performed between 4SP and 6SP and the fill opacity is changed from 0 to 100%, the results are above.

Test 2, Blend of a gray fill:

The 4SP layer and a solid gray layer of value 126 are blended together to see the changes in the values as the opacity of the gray layer is increased from 0% to 100%.

K%, RGB value fill (59, 126)	Zone 1	Zone 2	Zone 3	Zone 4
Layer 4SP	100, 0	74, 88	22, 210	0, 255
0	100, 0	74, 88	0, 255	0, 255
10	96, 13	72, 92	26, 202	6, 243
20	92, 30	71, 96	30, 194	12, 232
30	88, 44	69, 100	33, 187	18, 219
40	84, 59	68, 104	37, 178	24, 207
50	80, 71	66, 108	41, 170	30, 194
60	76, 83	65, 111	44, 162	36, 181
70	71, 95	64, 115	48, 153	42, 168
80	67, 105	62, 120	52, 145	47, 155
90	63, 117	61, 122	56, 135	53, 141
100	59, 126	59, 126	59, 126	59, 126

Table A1-2. Results of Test 2, where the first number in the cell is the luminosity and the second number is the gray value.

Test 3:

Use of the Difference Blend as interior opacity fill is increased in solid gray layer of value 126.

Layer 4SP	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
K% RGB value fill (59, 126)	100, 0	74, 88	22, 210	0, 255
0	100, 0	74, 88	22, 210	0, 255
10	96, 13	78, 76	27, 201	4, 246
20	92, 30	82, 64	31, 192	8, 239
30	88, 44	86, 51	35, 184	12, 231
40	84, 59	90, 36	39, 174	16, 222
50	80, 71	94, 20	43, 166	20, 214
60	76, 83	98, 4	47, 157	24, 206
70	71, 95	98, 5	51, 146	29, 197
80	67, 105	94, 22	55, 137	33, 188
90	63, 117	89, 39	59, 126	37, 179
100	59, 126	85, 52	63, 117	41, 170

Table A1-3. Results of Test 3, where the first number in the cell is the luminosity and the second number is the gray value.

Experiment #2: Image Calculation using the Subtraction Mode.

The objective was to see if the subtraction mode within the image calculation function would have an algorithm that would perform a straight algebraic subtraction without compensating for values that were too light or dark. An image of 100% opacity that contained a grid of various shades of gray was subtracted from an image of a solid gray value of 15. No inversions, offsets, or opacity changes were implemented within this mode (Figure A1-3).

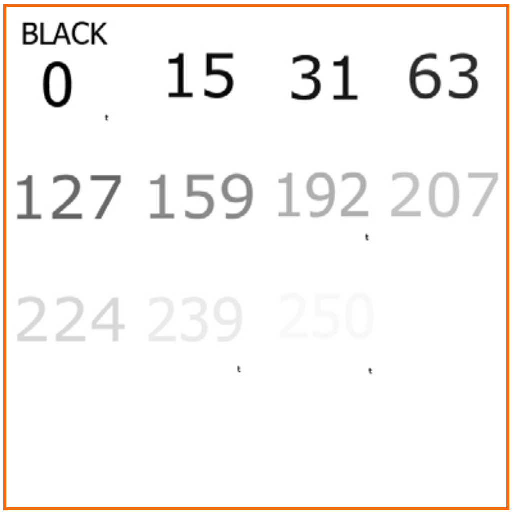


Figure A1- 3. Two test images. On the left, displays a series of gray values with the respective number assigned to it. The image on the right is a solid value of 15.

Results:

The subtraction mode was not a useful mode for the overall objective of subtracting images from the radiograph. Offsets within Table A1-4 show it is not a straight algebraic method of subtraction between the values within the images. In actual use, it is not obvious as to how to use this mode for the methodology. To make it work with this technique is much more involved than the addition mode in comparison. One might expect to subtract the two images by subtracting the solid gray layer from the layer with the numbers. To obtain the image below, it is just the opposite in actual practice (Figure A1-4).

100%,0,1	Subtract 15	Should be	Offset
0	0	0	0
15	0	0	0
31	12	16	-4
63	47	48	-1
127	115	112	3
159	148	144	4
192	181	177	4
208	197	193	4
224	215	209	6
239	230	224	6
250	240	235	5
255	246	240	6

Table A1-4. Results of subtracting the solid image of value 15 from the image of multiple gray values.

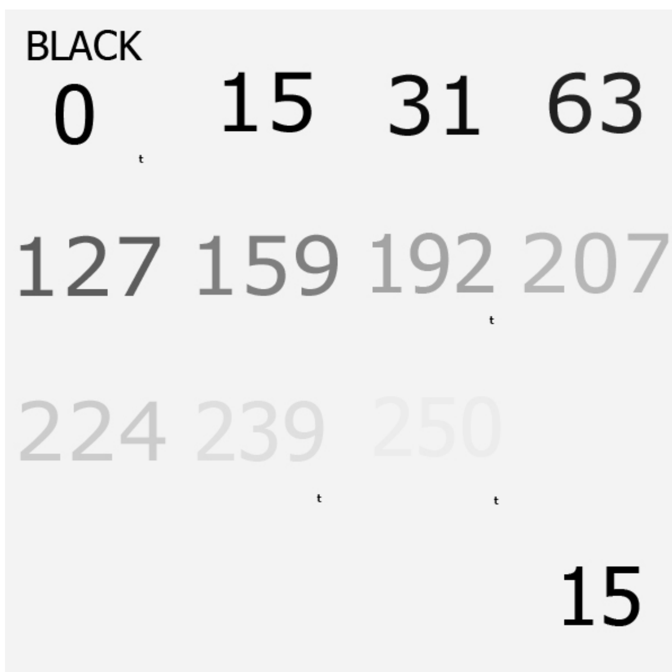


Figure A1- 4. The resulting image using the subtraction mode within the Image Calculation function. No inversions were used. Notice the light gray background instead of pure white.

Experiment #3: Image Calculation using the Addition Mode.

The objective was to see if the addition mode within the image calculation would have an algorithm that would not compensate for values too close to 0 or 255 as the subtraction mode would have done. An image with a RGB value of 15 was added to an image of 100% opacity that contained a grid of various shades of gray as shown above in Figure A1-5.

Results:

The addition mode performed well, despite the offsets that are displayed in Table A1-5. It sometimes added a little more to a value than expected, which was negligible. If a value was below 0 or above 255 after the calculation, the value would be clipped at 0 or 255 respectively. Clipping will not be expected since adding the opposite values will not yield a number smaller than 0 or larger than 255.

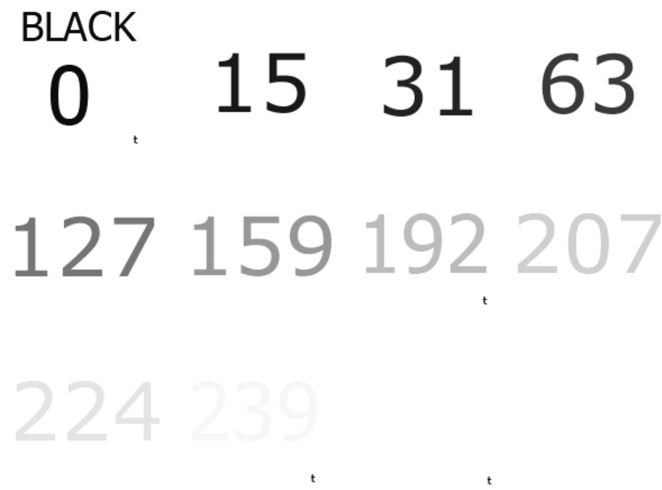


Figure A1- 5. The resulting image using the addition mode within the Image Calculation function. No inversions were used. Notice the numbers above 239 are pure white and are no longer seen.

100%,0,1	Addition 15	Should be	Difference
0	15	15	0
15	34	30	4
31	48	46	2
63	77	78	-1
127	139	142	-3
159	170	174	-4
192	202	207	-5
208	217	223	-6
224	234	239	-5
239	249	254	-5
250	255	265	-10
255	255	270	-15

Table A1-5. Results of subtracting the solid image of value 15 from the image of multiple gray values.

Experiment #4:

Attempts were made to use the scripting capabilities built into Photoshop. Photoshop has the capability to use AppleScript, Visual Basic Script, or JavaScript as an automation tool. Each language has a different syntax, but has the same limitations. Perusing the VBScript Scripting Reference and the Scripting guide, provided no access to manipulating layers or pixels in the way that it was needed.

Results:

Several attempts to find scripts online by way of forums, coding sites, and Photoshop help has proven that there is no way to manipulate layers through scripting. A simple algorithm to add and/or subtract two layers and output the results to another layer is all that is desired.

Experiment #5:

Attempts to create a plug-in using MS Visual Studios C++ have become a daunting task. The complexities of programming in an unfamiliar language, topped with the nomenclatures of Microsoft's version of C++, and a not-so-user-friendly interface, provides an incredible challenge. Adobe's SDK package is too complex, which would increase the time line of the project. Pixel math on two layers and an output of those after a subtraction is all that is desired.

Experiment #6:

Manual Manipulation of the image.

Attempts to forgo the proposed workflow to get the desired outcome is as follows, an alternate workflow.

1) Convert the color scan image to 8-bit grayscale.
2) Make sure the background layer containing the whole specimen is selected in the layer palette
3) Zoom into the area of interest
4) Click the Lasso Tool
5) Use the Wacom Drawing Tablet to carefully outline the entire bone of choice
6) Press Control-C to copy
7) Immediately press Control-V to paste the clipboard contents into a new layer, which will be above the background layer.
8) Make sure the new layer with only the bone of choice is selected
9) Zoom in really close with the overlapping bone edges in view
10) Carefully outline the an overlapping bone with the Lasso Tool
11) Choose one of the following methods to match the brightness of the overlapping bone to the parts that are not overlapping
    a. Image > Levels
    b. Image > Curves
    c. Image > Brightness/Contrast
    d. Image > Replace Color
    e. Image > Shadows/Highlights

f. Image > Exposure

12) Adjust the settings in the dialog box until the overlapping bone matches the shade of gray of the bone of choice.

13) Use the smudge tool to adjust the outline that is created between the bone of choice and overlapping bone

APPENDIX B

Series of Removed Bones

The results from removing each bone or set of bones are below. First the saved bones, isolated from the image are shown. Then the extraction from the image is shown.

Figure B1- 1. Original cropped grayscale radiograph.

Figure B1- 2. Humerus isolated from the radiograph and saved.

Figure B1- 3. Coracoid isolated from the radiograph and saved.

Figure B1- 4. Scapula isolated from the radiograph and saved.

Figure B1- 5. Furcula isolated from the radiograph and saved.

Figure B1- 6. Radius isolated from the radiograph and saved.

Figure B1- 7. Ulna isolated from the radiograph and saved.

Figure B1- 8. Radiale isolated from the radiograph and saved.

Figure B1- 9. Metacarpals isolated from the radiograph and saved.

Figure B1- 10. Digit isolated from the radiograph and saved.

Figure B1- 11. Phalanges isolated from the radiograph and saved.

Figure B1- 12. Various rib bones isolated from the radiograph and saved

Figure B1- 13. Humerus is extracted from the image, leaving overlapping coracoid, radius, and rib bones within the image.

Figure B1- 14. Coracoid is extracted from the image.

Figure B1- 15. Scapula is extracted from the image.

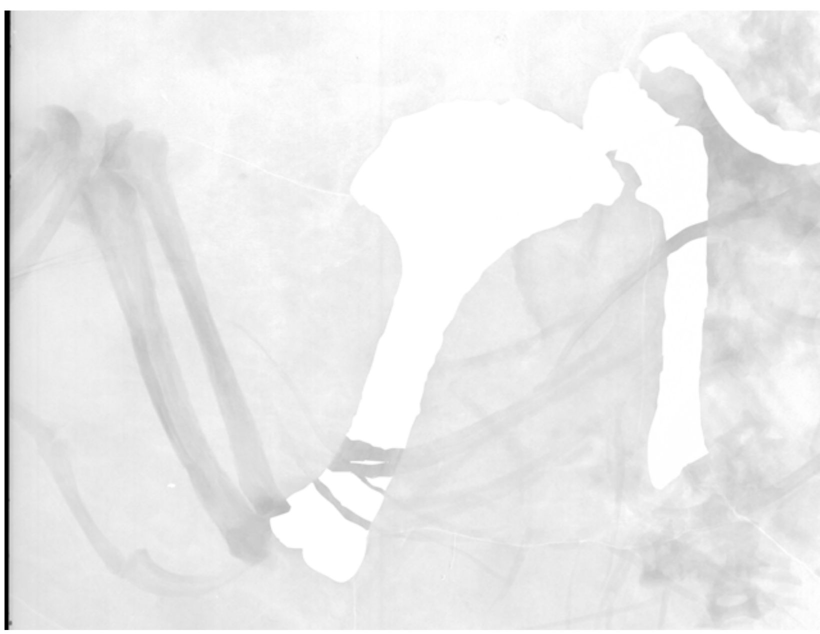


Figure B1- 16. Furcula is extracted from the image.

Figure B1- 17. Radius is extracted from the image.

Figure B1- 18. Ulna is extracted from the image.

Figure B1- 19. Metacarpals are extracted from the image.

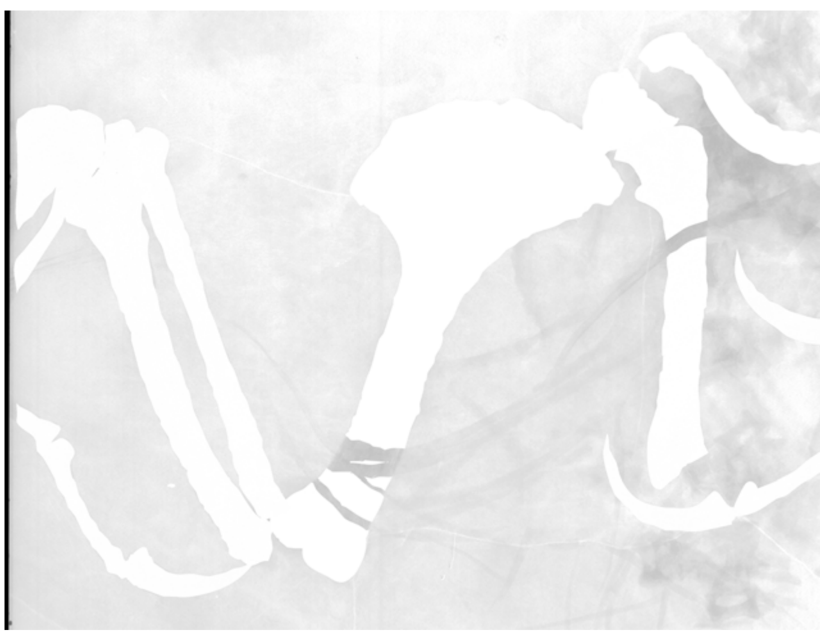


Figure B1- 20. Phalanges and Digits are extracted from the image.

Figure B1- 21. Rib bones are extracted from the image.

APPENDIX C

Using Photoshop as a Paleontology Tool.

There are several tools available and learning some of their capabilities will help speed up the reader's workflow. The following suggestions will help organize and use the Photoshop file format to the greatest extent.

Organization:

Photoshop can organize images within its file format. The images are set up in much the same way as files are in a directory structure within Windows explorer. They are referred to as groups, but are expressed as images within folders. To create a group of images, highlight each image within the file that you would like to group, right click and click group. Name the group appropriately. The reader can also create a group folder, name it, and drag images to the folder.

Marking with Symbols:

It is easy to create symbols that will help others understand what has been done or needs to be done before a preparation of a fossil. Tools such as the pencil, paint brush, and air brush all lend themselves well to marking the digitized radiograph. For example, if there are breakages along the rock matrix that affects the fossil, the reader can create a new layer and trace the crack or fill in the area of the fossils that are missing with a color. Create a legend within another layer to document the color representations.

The reader can also mark areas that are to be prepared or have already been prepared. The path tools are great for making outlines around an image. With a path, the reader can automatically trace it with a paint brush tool to better highlight it.

There is also a feature that will allow the reader to make shapes and symbols for repeated use. Once a system of communication is established, a standard set of symbols should be created for the paleontologist community.

Using Opacity:

Each image layer has the option of changing the opacity. The less opacity, the more translucent the image becomes. If the reader has several images that are matched to scale, such as the radiograph, filtered fluorescent images, a picture of the actual fossil, and other source material, the reader can then change the opacity on each in order to provide more accuracy in selecting bone shapes.

Filters:

Experiment with filters. There are many filters within Photoshop, each with several parameters that will affect the image in its own way. Make sure that the reader have the targeted image highlighted or create a selection of the image and then apply the filter. If the reader does not like a particular change, the history palette will allow the reader to undo multiple levels.

APPENDIX D

Software lists

Imaging Software:

Name	Publisher	Operating System	Website
Adobe Photoshop CS2	Adobe	Win/Mac	http://www.adobe.com
Paint Shop Pro	Corel	Win	http://www.corel.com
Canvas	ACDSEE	Win/Mac	http://www.acdamerica.com
PhotoLine	Computerinsel GmbH	Win/Mac	http://www.pl32.com
GIMP	N/A	Linux/Unix/Win/Mac	http://www.gimp.org
MatLAB	Mathworks	Linux/Unix/Win	http://www.mathworks.com
Lightwave 3-D	Newtek	Win/Mac	http://www.newtek.com
Maya 3-D	Autodesk	Win/Mac	http://usa.autodesk.com
3D Studio Max	Autodesk	Win/Mac	http://usa.autodesk.com
Blender 3-D	Blender	Linux/Unix/Win/Mac	http://www.blender.org

Table D1-1. Imaging software used as a potential alternative to Photoshop.

Database Software:

Name	Publisher	Operating System	Website
Access	Microsoft	Win/Mac	http://www.microsoft.com
Oracle	Oracle	Many	http://www.oracle.com
SQL		Many	
MySQL	MySQL Inc.	Many	http://www.mysql.com

Table D1-2. Database software that can be used for file organization, searches and recall.

Publishing Software:

Name	Publisher	Operating System	Website
Illustrator	Adobe	Win/Mac	http://www.adobe.com
Acrobat Professional	Adobe	Win/Mac	http://www.adobe.com
Microsoft Office	Microsoft	Win/Mac	http://www.microsoft.com

Table D1-3. Publishing software for integrating images into written documents.

APPENDIX E

Interpretation and Sharing Information using the PACS system

The overall idea is to create a system of interpretation for paleontology much like is done in geological interpretation. A clear technique and set of conventions should be created for better communications amongst paleontologist using modern technologies. Another future goal is to create a cost effective method of interpretation using commercial off-the-shelf software that can provide some of the same functionality as software used in the medical profession.

Current Technology

Photoshop CS2 can perform some of the same tasks that medical doctors can on X-rays using their automated software for computed radiography. Hospitals are currently using digital x-rays that are precise and create digital images automatically, reducing the amount of radiation dosages for patients and creating high resolution images (Gater, 2004: 367-377). Digital images can be manipulated to adjust contrast and density after the image is created. At the moment, PACS, is a system used to manipulate x-ray images. (personal comm., T. Sareussen and R. Luttrell 2005) They can remove bones from the X-ray images, which leaves a white space just as Photoshop does.

The PACS system is actually an infrastructure that allows for the communication of doctor interpretation of X-ray scans through the internet and has a database for storage of the images and records. We have not delved into the database aspect. Image organization within the Photoshop file, within the storage drive, and naming conventions can all be done on a per site basis.

Interpretation

It is necessary to use multiple sources of data for interpretation. It would be virtually impossible to make certain distinctions between bones and other artifacts of the x-ray image without other sources of data to compare to. Just as geologists that look for oil use a combination of processed seismic 2-D or 3-D surveys, velocity data, checkshot data, well log data, geo-reference data, well markers, bio-strategraphic information, horizons that were previously interpreted by someone else, and possibly fault data, a paleontologist would need a similar workflow. While interpreting x-ray images to extract the bones, it is suggested that the actual fossil be present. In addition to having the fossil present, high quality x-rays, stereo pair images placed on a light table using a stereo viewer, microscope (video), and drawings of the same bones from different specimens would also be a great advantage.

Future Technology

There may be ways to separate bones from the image, while leaving actual data from an overlapping bone visible. The x-ray would have to be of the highest quality and capture as much information as possible. One way to fool the eye would be to use the thickness of the actual bone mass as a ratio to the pixel value seen on the image.

Subtracting a certain density value should leave behind a lesser pixel value equal to the ratio of the remaining overlapping material. For consistency along the bone, correlation and coherency filters would have to be used along the bone to establish the parts that actually represented only the bone that is to be removed. A major goal of the project is to eventually create software that will remove the bone images at the push of a button after the paleontologist defines the shape of the bone. If a ghost image of the selected bone remains, on either the isolated bone or image, the command is undone and the parameters are then changed so that the automation can be initiated once again.

Using professional off-the-shelf commercial software is just the beginning stages. The writer imagines the use of highly detailed X-rays and MRI images of fossils to get 3-D interpretations with software that is normally used to interpret seismic data. Programs like Paradigm's Voxelgeo and Earth Decision's Gocad are two seismic interpretation softwares that have the ability to mask certain color values that represent values of amplitude characteristics. If a 3-D image is placed into these softwares, one can isolate certain areas and shapes that are found within the image. The writer has seen this performed with Voxelgeo on an MRI image of a human being, where the same color values (densities in our case) would be isolated and everything else is transparent. The veins and arteries were isolated, for example, by finding their color value and making everything else transparent. The image can be rotated to see various perspectives of the specimen (Seeram, 2004: 435-452). Most geologic interpretation programs are way too expensive to purchase just for trial and error unfortunately.

The writer also suspects that Matlab could be a cheap alternative to purchasing expensive geologic interpretation software. Matlab uses matrices to perform most of its calculations and has a superb 3-D graphics engine. It could possibly take MRI data, which is just a TIFF file with multiple imbedded images, distill them, convert the pixel values into a volume format and then coded to show only certain ranges of pixel values. Creating the MRI may be the most costly aspect of this process.

Recommendations

Crisp, high resolution x-ray images are very desirable. A combination of software may be useful to get a full digital interpretation. A software package for graphical manipulation, database of images, metadata on those images, and another package for 3-D interpretation would be extremely useful. A combination of Adobe Photoshop CS2, Adobe Illustrator CS2, Microsoft Access, and Matlab could possibly create a complete interpretation system.

A set of naming conventions could also be established according to geologic age, general geographic location, rock formation, and specific location (Lofgren, 2001). This would be similar to core data, where pictures are taken along a core and stored with labels for every variation of rock within the core. The same can be done within the very same Photoshop file that contains the fossil one is interpreting. Because Photoshop CS2 can have group folders within the file, it is possible to include map plots, maps of the location, field and locality numbers, and digital identification labels that the reader can hide when not needed (Compton, 1985: 372-378). If one needs to send a picture to a colleague, labels can be revealed, and then the onscreen image exported to a JPEG file and emailed.

While interpreting, it may be useful to have a group of symbols that tell the viewer what may have happened to the fossil during preparation. Photoshop has the ability to store custom made shapes in a file for later retrieval. These shape files can be distributed amongst paleontologists so that everyone is using the same shapes to identify original cracks in the matrix for example, or fractures in the bone mass due to shipment of the fossil.

A well placed high resolution photograph of the fossil can be placed in a layer beneath the X-rayed layers with an adjusted opacity. Once sized to match the x-ray, it can be used to better interpret the x-ray image. Filters can also be used on the photograph for various reasons, possibly edge detections to match those of an edge detection filtered on the x-ray image.

Illustrator CS2 could come in handy when outlining bones to get a much more accurate shape of the bones. Most 3-D packages will accept an Illustrator file, which can then be extrapolated from a 2-D to a 3-D object. Illustrator comes within most of Adobe's creative suite packages alongside Photoshop CS2. Academic pricing makes the suite packages much more affordable.

Because the writer is not experienced in database management or coding, he is not sure if Microsoft Access will link to actual files. If it can, it makes it ideal to use with the reader's filing system because metadata can then be used to describe images and recall them with search features. Microsoft Access comes with some versions of Microsoft Office. There are also versions of Microsoft SQL that may be available for purchase or come with certain software technologies provided by Microsoft.

Finally, Matlab would be a great tool purely based on it's expandability as an analysis tool. There are many scripts out there for creating volumes from images and performing certain filter operations on images. Matlab would give more control over image manipulation and because it has 3-D graphic rendering aspects, it is ideal for multiple data sources. The only drawback would be the amount of coding involved or searching for just the right code from websites. Mathworks, the publisher of Matlab, has many modules for purchase for various disciplines.

Communications

It would be ideal for each institution that would like to share data to have their own internet server with query searches so that paleontologists from one institution to another can share data more efficiently. (This is why having naming conventions and standards for files and data within the files such an important issue.) Imagine being able to find a particular fossil in the field, sending an email to museums or colleges with resident paleontologist and having them grant access to their database to find pictures that resemble the reader's fossil. Having a virtual lab will also help reduce the costs of transporting a specimen. Many people in various places can interpret them at one time, which will save time and money.

Unfortunately, large files may be hard to transfer in a reasonable amount of time. If this is the case, maybe CDs or DVDs could be an option for mailing. Newer media is making it easy to store larger data sets. Secure Digital cards, for example, come in various physical sizes as well as storage sizes. The highest storage size at the moment to date is 4 GB of data, which would be more than enough to hold a 3-D volume and PSD files. They are also very light in weight and inexpensive.

APPENDIX F

Complete Technique Workflow

1. Open Photoshop.
2. Open x-ray image of fossil.
3. Create multiple layer copies of the x-ray image.
4. Manipulate the layer copies to make the image easier to interpret (change saturation, hue, use filter effects, etc).
5. Make at least one layer completely grayscale.
6. Copy the grayscale layer and rename for later manipulation.

Selecting Bones:

7. Use the lasso tool to outline the Humerus for example.
8. Click the Paths tab to activate the Paths palette.
9. Click the “Make workpath from selection” button.
10. Double click the work path and rename it to the name of the bone. (the reader must do this to save it, otherwise the workpath is changed upon clicking the “Make workpath from selection” button again)
11. Deselect the selected path by clicking an empty area within the Paths palette.
12. Repeat steps 7-11 above for all other bones.

Isolating the target bone to be subtracted:

13. Click on the Layers Tab to activate the Layers palette.
14. Click on the copy of the grayscale layer making sure it is the active layer.
15. Click on the Paths Tab for the Paths palette.

16. Select the first path of the bone in the list.
17. Click on the “Load path as a selection” button.
18. Copy the selection, use Control-C.
19. Immediately press Control-V to create a new layer with just that bone.
20. Switch to the Layer palette so that the reader can rename the isolated bone layer with the name of the bone.
21. Select the grayscale image again to make it active again.
22. Repeat steps 15-20 until all paths have been used to create new layers of isolated bones.

Selecting overlapping sections:

23. Change to the layers palette.
24. Choose the isolated bone layer of the bone the reader wish to subtract from the image.
25. Make a copy of the isolated bone layer so that overlapping bones can be painted over. (The reader want to make copies so that the reader don’t have to go back and recreate the isolated bone layer)
26. Click any marquee tool and click anywhere on the image once to clear any selection or press Control-D.
27. When the reader are ready to select bones that overlap the target bone to be subtracted, select all overlapping bones by holding the control and shift keys and selecting each path within the Paths palette. The reader should see a marquee around all overlapping bones the reader has selected.

28. Hold Control, Shift, and Alt at the same time. Click the target bone in the Paths palette. The reader should see only the portions that overlap that bone surrounded by the marquee.

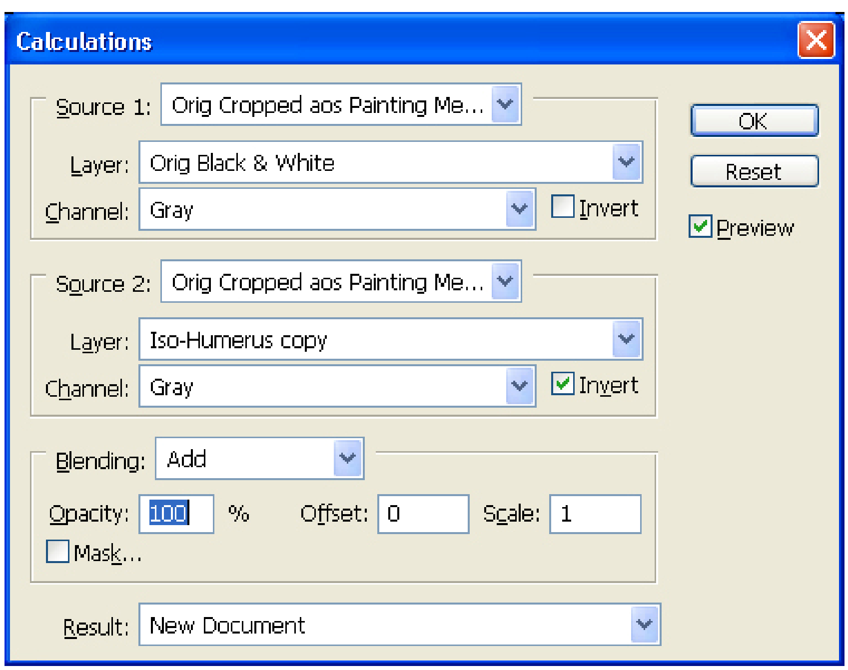
Painting the overlaps:

29. Use the Paint Bucket Tool to fill the selected areas with an RGB value between 240 and 255. To do this, click on the foreground color and change each color channel R,G,B with the chosen value. Experiment with the value, but should be a shade of gray. This means that each color channel has the same chosen number.

Subtracting the bone from the layer:

30. Click on the Layers Tab for the Layers palette.

31. From the menu, click Image > Calculations. Place similar parameters in the calculations dialog box shown below:



32. Within the new document created, go to Image > Mode and select grayscale.

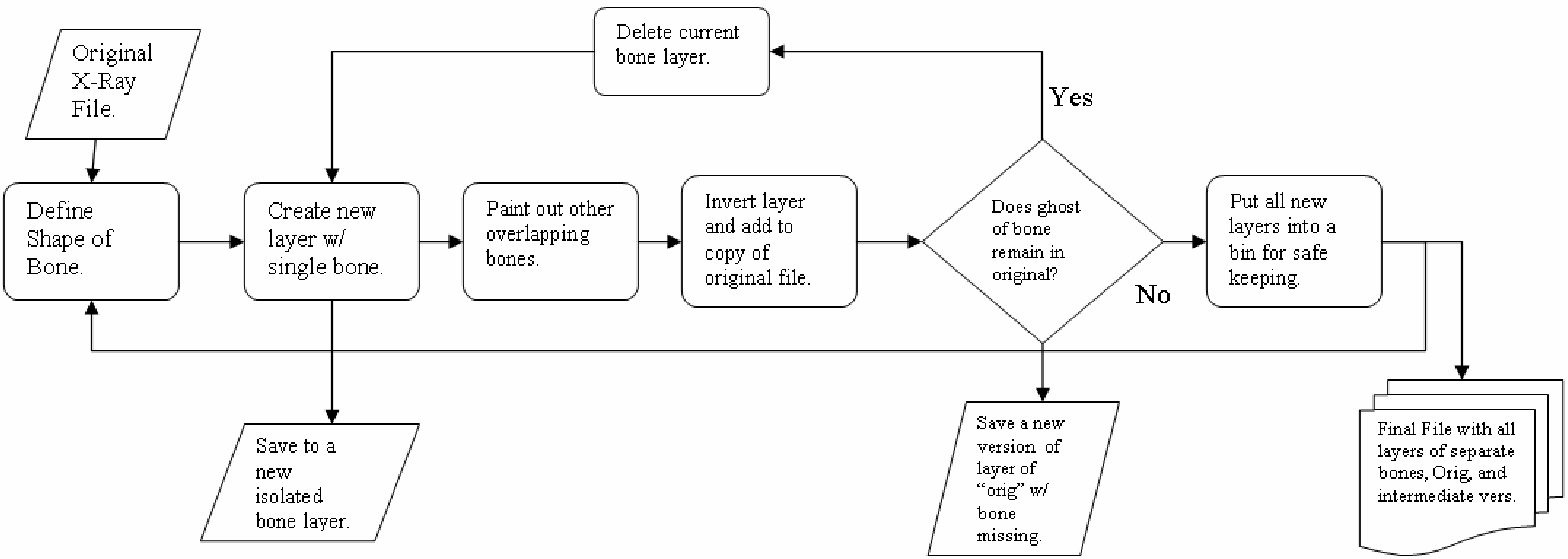
33. With the project image window visible and the new document created visible, drag the new document layer from the layer palette to the window of the project. (You may have to reposition the new layer to match that of the project)
34. This newly imported layer will now be the source 1 layer for the next subtraction instead of the original grayscale copy.

Organizing the data:

35. In the layer palette, you can create groups and groups within groups.
36. Naming conventions also help so that you can distinguish between various images within your project.

APPENDIX G:

Digital Image Bone Extraction Process



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Sirel was born and raised in Metairie, Louisiana. He attended Green Park Elementary, St. Lawrence the Martyr, T.H. Harris middle school and graduated in 1994 from East Jefferson high school in Metairie, Louisiana. Sirel would later find himself at Louisiana State University for two years as a double major in Electrical and Computer Engineering, from 1994-1996. His interests were always computer and art related, even before the age of nine. When he became serious about school, he then returned from Baton Rouge to attend the University of New Orleans. He landed his first job ever in 1997 as a computer helpdesk technician fielding computer questions in labs and by phone. Money became a priority at this point, so he landed another job with a contractor for the Department of Defense as a graphic specialist, while still working his campus job and attending school for Electrical Engineering. He also made web pages as a hobby at that time and freelanced whenever he could for various companies. Sirel has never applied for a school loan, having saved up $10,000 by graduation time in 2000 from working the two jobs simultaneously and designing web pages.

After graduation, Sirel looked for a job in a market that was oversaturated with engineers at the time. He then sought to help his parents renovate their rental properties for a year. Then, sometime after the 9/11 tragedy, Dr. Laura Serpa called to inquire about his employment status and to see if he would pursue a Masters in Geophysics. Dr. Laura is a persistent recruiter of minorities and tried her best to persuade Sirel to pursue a degree in Geophysics ever since they first met back in 1997. Sirel promptly said "No" at first, but gave in after accepting an invitation to help a graduate student conduct research in Nevada and shoot seismic in Death Valley, CA for a geophysics class (winter of 2001).

Since then, Sirel has worked with ExxonMobil (2004 & 2006), the Minerals Management Service (2003), and Petroleum GeoServices as a geophysicist (2005). During 2003, he joined many societies, most notably NOGS, as an AAPG student chapter chairperson representing UNO from 2004-2006. Much of his summers have been either interning with the aforementioned companies or traveling out west as a chaperone for the UNO Minority Student Field Trips since 1998. The field trips have run for over 30 years consecutively and have been instrumental in promoting geology and geophysics to high school students, making it possibly the only program of its kind in the country.

Sirel has made many contacts within the oil industry and is very grateful for earning his degree at a time when the country's primary focus is on oil conservation or lack thereof. He hopes to apply his engineering, computer, art, and geology skills to assist in resource conservation. Sirel will start employment with ExxonMobil in January of 2007 and will continue his hobbies in music, art, poetry, videography, and more.

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Thesis Examination Committee:
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Committee Member, Laura Serpa, Ph.D.
Committee Member, Mostafa Sarwar, Ph. D.

*Fulltime employment with ExxonMobil starting 2007.