Journal of the American Society of Questioned Document Examiners, Inc.
Volume 16, Number 1, June 2013

An "Ideal" Methodology for Manually Assembling Crosscut Shredded Documents

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This paper outlines a procedure the author developed while working an "ideal" case—the reassembly of a small bag of crosscut shredded documents. The shredded pieces, or "shred" were made up of several colors of paper, with a variety of handwritten or printed entries.

The author discovered that, by making some rudimentary measurements of the shredded particles, assembling a small portion of a document, and observing how the crosscuts occurred, it was possible to predict and visualize the pattern into which the document was shredded. With this pattern, and other techniques used to sort and arrange the shredded pieces, the manual reassembly of the document was successfully completed.

Key words: Shredded documents, document reconstruction, paper shredder, shred

Introduction

The methodology outlined in this paper was developed while working a case received late in 2011. The evidence consisted of a small bag of shredded documents (about the size of a sofa pillow) that required reassembly. The bag was believed to contain lists of names and Social Security Numbers that were used in filing false tax returns. Inside was paper shred of several colors and types, some pieces bearing handwriting and others bearing machine printing. Several of the documents were Post-It™ notes, some of which were apparently stuck to each other before shredding, while some were attached to other documents. Due to the random position of the notes, they became shredded in different orientations to the shredder opening or "throat."

Numerous references over the years explain methods for sorting and handling torn documents of various types (including Osborn 1929, Harrison 1958/1981, Hilton 1982, Peace 1982, Gencavage 1986, Morton 1989/90, Hammond 1994, Levinson 2001, Vastrick 2004, and Kelly 2006). However, only three references could be found that provide specific techniques for assembling machine-shredded documents (Schuetzner and Commella 1997, Vail 1978, and Nobles and White 2008).

In the last decade, most papers dealing with this subject pertain to the automated or computer-assisted reassembly of documents. On the more theoretical side are a wide variety of highly technical papers about the computer-assisted/automated methods of reassembling shredded papers, torn papers, and jigsaw puzzles (including Ukovich and others 2004, Justino and others 2006, Skeoch 2006, Prandstatter and Raidl 2008, and DeSmet 2008). On the more practical side are the following:

- In 2002, Randy Gibson used Adobe Photoshop to manipulate scanned images of shredded particles (recounted in Herbertson 2002).
- The FBI commissioned a software program to assist in this type of work. "MatchMaker" is "a computer-assisted reconstruction

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system used to facilitate the reassembly of cross-cut shredded documents." (FBI 2007). Brought online in 2007, it assists an examiner in matching shredded documents that bear machine-printing.

- In October 2011, the US Defense Advanced Research Projects Agency (DARPA) opened a contest to reassemble five crosscut shredded documents and answer questions about the contents to win a $50,000 prize. (A small team from San Francisco completed the task in 600 man-hours, employing "custom-coded, computer-vision algorithms to suggest fragment pairings to human assemblers for verification." (DARPA 2011, Aron 2011, and Boyle 2011).
- And one commercial program currently exists, called, "Unshredder - the Shredded Document Reconstruction System." Advertised as "the first commercial document reconstruction tool in the world," it claims to be able to reconstruct strip cut or crosscut shred, as well as torn documents, and it is promoted as being easily learned for anyone with basic computer skills ([Anonymous] 2013).

Despite the availability of automated techniques, most forensic document examiners do not have experience with or access to computer-assisted methods, so manual assembly methods are employed. ("Reconstruction of ripped-up documents… is often carried out using various home-spun or loosely defined procedures… in practice, forensic examiners most often resort to manual reconstruction procedures," DeSmet 2008, p.124).

Fortunately, if an examiner ever completed a jigsaw puzzle, then he or she has rudimentary experience in document reassembly.

Jigsaw Puzzle Assembly 101

The author may have first learned this basic method from his grandmother, who always had a picture puzzle on a card table in the living room at some stage of reassembly. At the risk of stating the obvious, the steps in assembling a picture puzzle are to:

a. spread all of the pieces out;
b. turn pieces over so the same side is up;
c. locate border and corner pieces;
d. assemble the borders;
e. associate pieces of similar designs and colors;
f. start assembling, trying to fit pieces by trial and error; and
g. finish when the picture is complete.

A forensic document examiner, however, encounters the following difficulties in reassembling shredded documents:

- many pieces are exactly the same size and shape;
- the pieces are rather small to begin with;
- many pieces are likely to be curled up and/or stuck together;
- the pieces can be rather fragile and hard to handle;
- pieces may be missing (either stuck in the shredder teeth, or clinging to the bin due to static electricity and never retrieved); and
- most critically, there is usually no reference image or design to work toward.

The problem is akin to emptying several picture puzzles onto a table top, and throwing away the boxes.

The methodology presented in this paper is "ideal" for cases involving a small amount of shred in many colors of paper/ink, in which few or no pieces appear to be missing. If followed, it may allow the reassembly of an entire document or documents to their original condition or configuration. This same methodology, however, would not be the most practical, cost-effective or "ideal" for a more typical case involving a large trash bag of shred confiscated from a shredder bin during the execution of a search warrant. Nevertheless, it includes steps an examiner may find helpful in any case.

The methodology

1. Sorting shredded pieces (aka shred/shreds) into subgroups

While experts in the shredder industry have a variety of terms for the shredded pieces, e.g., "fragments" or "particles" (McDonald and Olson, in this issue), shredder machine brochures usually use the words "shred" or "shreds" (Cummins Allison 2012), which are terms the author prefers.

Separate shreds by visual means into various subgroups, such as:

- colored paper vs. white paper;
- lined paper vs. unlined;
- machine-printed vs. handwritten document;
- typewriting vs. other printing process;
- handwriting vs. hand printing; and
- handwriting separated by color of the ink.

(See Schuetzner and Commella 1997, Hammond 1994, and Vail 1978, on sorting shredded or torn documents.)

As Vail states, "the process should… reduce each pile to its lowest common denominator" (Vail 1978, p.9). It helps to have a collection of containers large enough to hold each subgroup (the author used various-sized mailing boxes—the larger were the size of department store shirt boxes and the smaller were cigar-box size.)

While handling the evidence, one might take care to protect it so fingerprints or DNA might be developed from the reassembled document(s). Consider wearing gloves and using a forceps to handle and manipulate the shreds, which can be done with practice, but will definitely increase assembly time.

The use of ultraviolet (UV) illumination and/or an alternate light source may assist with the initial sorting to separate papers that fluoresce differently (for example, under UV, the adhesive strip at the top of a 3M Post-It™ note will fluoresce brightly, which helps to identify the top edge). When sorting shred from toner-printed documents, a magnetic properties detector can be used to separate those printed with magnetic toner from those printed with non-magnetic toner.

It is likely that pieces of shred will be found that are stuck together by virtue of their original documents having been shredded at the same time. One manufacturer calls them "stacks" or "packets" (Hartnett and Romanovich 2012). The author named the individual pieces within a stack "clones," because they were created at the same time. A stack of clones may consist of shred of several different colors and/or types. It is recommended that the stacks be kept intact and segregated as a group for the time being. Their handling and use will be explained later.

2. Selecting a related subgroup of shreds for assembly

After the initial sort (which is likely to take the longest of any of these steps), collect a single subgroup of shreds with similar characteristics to begin assembling. (The author chose a small pile of pink Post-it™ shred, which was the subgroup with the fewest number of pieces. One may, instead, begin with a pile believed to contain the documents most important to the investigation.)

3. Flattening the shreds and laying them out

Many crosscut shreds will have curled edges which make them difficult to handle and view. Large numbers of them may be flattened by pressing them together under sheets of glass. The author supplemented this method with a slightly more time-consuming technique for the most deformed individual shreds. It is basically the reverse of the technique used to make a ribbon curl on a gift package - holding one end of a shred in one's fingers and rubbing along the length of the piece with a forceps, while turning slightly in the opposite direction of the curled end (Figure 1). This method needs to be used with care, because it may tear shred from thinner paper stock.

A workspace needs to be selected for the layout and reassembly. A large area in a separate room with a lockable door is preferable. It is recommended to lay out the shreds in trays or shallow containers (e.g., paper carton lids, document protector boxes, lipped baking trays, map drawers, etc.). This allows them to be stacked for temporary storage and offers protection from drafts and passersby. The ultimate goal is to have an

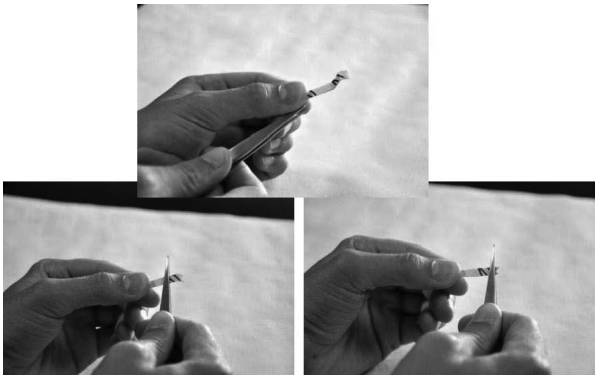

Figure 1. A bent shred being uncurled with forceps.

Figure 2. Shreds being sorted and laid out in categories under glass sheets and in shallow box tops.

organized work area of sorted shreds so that once document assembly has begun, one can easily locate a particular piece (Figure 2).

4. Orienting the "arrowheads"

While laying the shreds out, one may notice that they have a distinctive shape. If the shredder used had v-shaped blades, it may produce shred with a convex "arrowhead" or caret (^) shape at one end and/or a concave notched "arrow tail" shape at the other (Figure 3). Research has shown that: 1) all of the arrowheads will point in the same direction on the same document; and 2) this is the direction in which the document was shredded (McDonald and Olson, in this issue).

Therefore, if arrowheads/tails are found during the layout, orient the shreds with the arrows pointing in the same direction. (Unfortunately, all shredders do not use v-shaped blades. If a different type of shredder has been used, there may be very little indication of "directionality" among the shreds.)

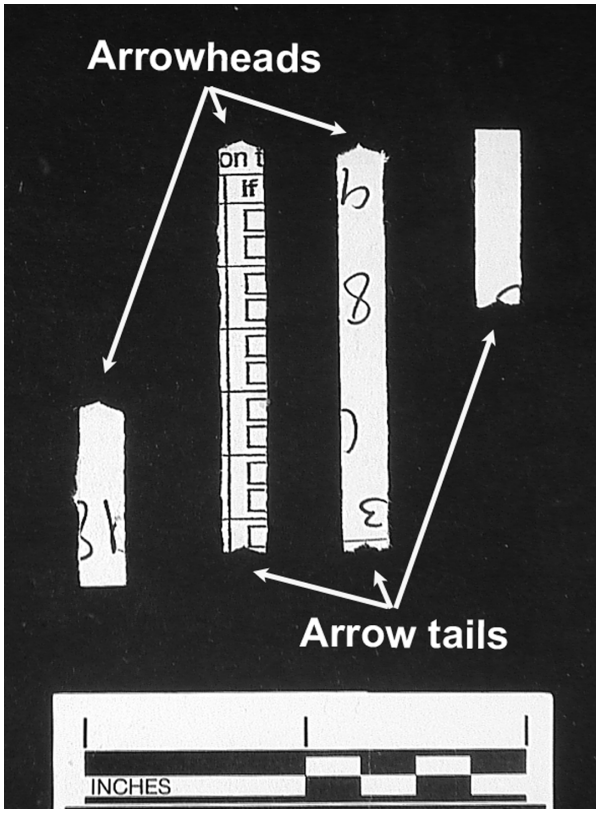

Figure 3. Shreds oriented in the same direction (upward) with arrowheads and arrow tails indicated.

5. Turning the shreds the same side up

Turn all of the pieces over so that the same side appears to be up. Shreds that are "double sided," that is, with writing or printing on both sides, should be segregated and prepped using the procedure below.

Double-sided shreds have ink or printing on both sides. The examiner will want to have both sides readily visible when searching for a specific piece. This can be accomplished most easily by placing them between sheets of glass, which allows for the easy examination of either side. To prevent having to repeatedly turn the sheets over for examination, scan both sides in color at 300 dpi and make a print of each side. At the reassembly workspace, the glass sheets can be placed one side up and the print of the other side placed next to it (Figure 4).

6. Locating and segregating border shreds

This step is most useful if one has a limited amount of shreds and/or one is attempting to

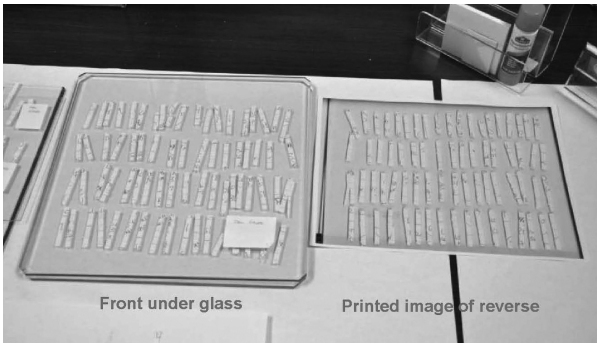

Figure 4. Double-sided shreds: at left, under glass facing up, at right, a print of the reverse side.

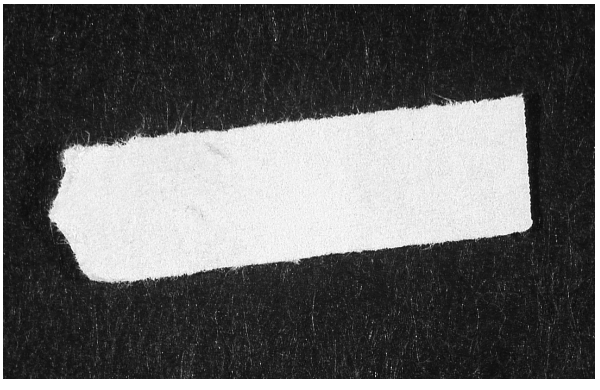

Figure 5. A piece of border shred – the rightmost edge is the paper machine-cut border, while the other three cuts were made by the shredder.

assemble the entire document. Locate the edge pieces and set them aside. It may be necessary to examine the edges of what appear to be border shred with a microscope of 7x-30x power. A cut edge made at a paper factory is typically sharp and uniform, with a slight cove or curve to it, while a shredder machine-cut edge is ragged and irregular in comparison (Figure 5).

Border pieces can be further sorted by observing the arrowheads or arrow tails, if present, to determine on which side of the document they belong. Shreds with a flat edge on one end and an arrow tail on the other were on the leading edge of the document being shredded, while shreds with an arrowhead at one end and a flat edge at the other were on the trailing edge (see Figure 3—the edge piece on the far left is from the bottom border, while the piece on the far right is from the top border).

7. Locating and segregating corner shreds

While locating the borders, one will also encounter corner pieces. An advantage in locating all of the corners is that one can estimate how many documents are in this subgroup (by counting the number of corners and dividing by four). If the number is not evenly divisible by four, a piece may have been overlooked during the sorting process, there may be pieces that were not recovered from the bag or bin, or one or more of the documents shredded may not have been square or rectangular. In the author's case, twenty pink Post-It™ note corners were found, so there were (at least) five notes to be assembled.

8. Sorting border shred by determining and/or comparing border angles

This step may be useful if there are multiple documents of the same paper type (e.g., similarly colored Post-It™ notes) that were shredded in a variety of positions relative to the shredder throat. It involves sorting the border pieces by the angle formed between the machine-cut edge(s) and the shredded edge(s). This angle was determined by the orientation of the paper as it went through the shredder.

Most documents are usually shredded longitudinally (in a portrait orientation) because the throat of many common shredders is between 9-11 inches wide (McDonald and Olson, in this issue—some common standard-size shredder throats varied from 22.90-26.04 cm, or 9.02-10.25 in.) If a document is folded, or smaller than 8 ½ inches wide, it may have gone through the shredder at a different angle, and not perpendicular to the shredder throat. And if the document is a Post-It™ note, it may have been placed on a document in any angle relative to the document axis.

Measuring the angles can be done manually with a clear plastic protractor, or by using an imaging instrument like a Video Spectral Comparator (VSC). Some geometry rules concerning the angles found are (Figure 6a):

- The interior and exterior angles on the same piece of shred will always equal 180 degrees (A and 180 minus A).
- The angle directly opposite angle A on a parallel side of the document will also be a 180 degree complement (or 180-A).
- The angle directly opposite angle A on an adjacent, perpendicular side will be a 90 degree complement (or 90-A).

Ultimately, only one angle (A) on any shred need be measured—the remaining angles occurring on the document can all be calculated.

After measuring the angles, or at least comparing them, sort and separate the border shreds by the cut angle(s). All of the pieces with the same angle and its complement(s) may belong to the same document, but shreds with angles different from those will definitely belong to a different document (unless the document was folded or wrinkled before or during shredding) (Figures 6a and 6b).

9. Locating and processing clones

Collect the stacks of clones that might include shreds from this subgroup. It was recommended to keep them intact until this step for two reasons:

1. if they are from a group of documents shredded in the same event, it may be possible to reassemble all of these documents at the same time; and
2. if they are from a document and its attached Post-It™ note(s), one may be able to reassemble them in their original configuration.

Clones are ideally handled by:

a. placing the stacks between sheets of glass;
b. imaging them on both sides (e.g., with a color scanner at 300dpi);
c. separating the stacks, but preserving their orientation; and
d. imaging both sides again.

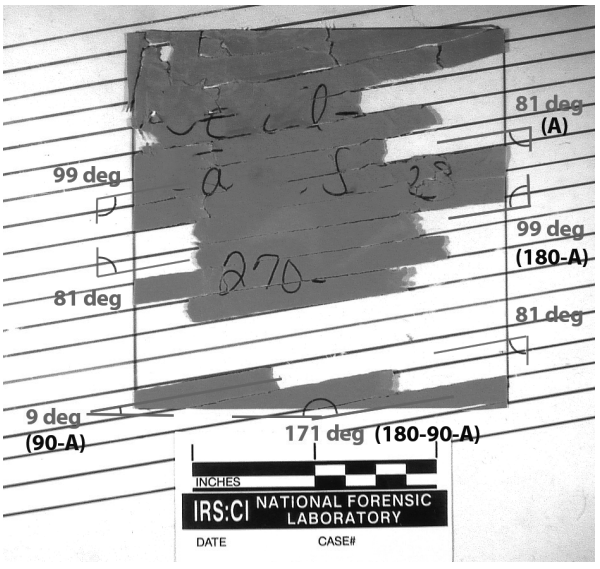

Figure 6a. Post-It™ note shredded at an angle. Border angles on shred from this note will be either 81, 99, 9, or 171 degrees.

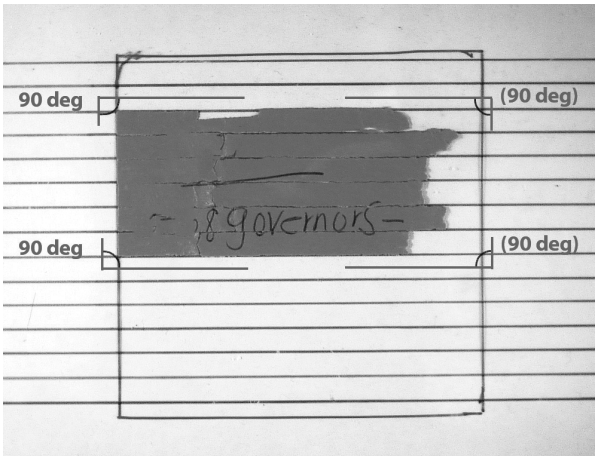

Figure 6b. Post-It™ note shredded sideways. Border angles are all 90 degrees.

The clones can either be left under glass until needed for assembly (if enough plates are available), or they can be removed and inter-sorted with shreds from their appropriate subgroup. The scanned images can be printed for use in locating the pieces later.

10. Measuring the mean shred width

Measure the width (narrowest dimension) of several shreds and determine the mean value. This width results from the cut that is made longitudinally through the document, like a strip cut in a strip cut shredder ("Every particle [in a cross-cut shredded document] is essentially strip cut." Hartnett and Romanovich 2012). This width should be the same for all shreds cut by the same machine. (Exceptions might occur if the document became twisted as it was going through the shredder, or if a cut was ineffective and the piece was torn from the rest of the document.) This mean width will be used to make a grid of parallel lines (the "strip cut grid" or "alignment grid") in step 14.

11. Measuring/comparing the mean shred length(s)

Many shredders produce "internal shred" (i.e., non-border pieces) of only one length (McDonald and Olson, in this issue). Border shreds will be of a variety of lengths, but there will be a maximum length for internal pieces, which is specified by the shredder manufacturer. In the author's case, however, the internal shreds were discovered to be of two discrete lengths (approximately 1½ inches and 1¾ inches).

One may wish to measure the lengths of several internal shreds to determine if they are more than one length, and sort them by size, if more than one length is present.

12. Associating shreds bearing similar texts or designs

While proceeding through all the steps above, a few potential matches will be found among shreds with similar writing, printing, or designs. ("As the pieces are individually tacked down, a pattern will emerge." Vail 1978, p.9.) These groups of associated shreds can be placed temporarily:

- under glass;
- within a document protector (Schuetzner and Commella 1997);
- on a sheet made tacky with glue stick/ removable adhesive;
- using strips of low-tack adhesive tape; or
- on sheets of a commercially-made low-tack self-adhesive product (Nobles and White 2008, and Parker 2012).

To avoid wasting time on a document that is not important to the case, as soon as enough shreds are associated on any one document to render it legible, it may be advisable to consult with the submitter to determine if it is worthwhile to continue its assembly (Schuetzner and Commella 1997).

13. Beginning the document assembly

With the shreds sorted and organized for easy retrieval, assembly can begin.

13a. Select a cluster of associated shreds bearing a visible horizontal or vertical reference line, because a starting point is needed from which to assemble the document. Ideally, this reference line will be one of the document borders, but assembly could begin from any printed horizontal or vertical ruling within a document (e.g., a red two-line vertical margin ruling) (Figure 7).

13b. Choose a medium/substrate on which to assemble the first document.

Vail recommended assembling on cardboard with pins (Vail 1978); however, a transparent substrate (e.g., a glass or acetate sheet, transparency film, or side-loading plastic document protector) has many more advantages, one being that both sides of the document can be viewed as it is being assembled (Osborn 1929, Harrison 1958). (The author assembled most of his documents on the inside of document protectors, as they are light, strong, provide protection, can easily be turned over, are able to be written on with permanent markers, and can be sealed shut for storage or handling - see also Schuetzner and Commella 1997. The author also assembled a few documents between individual sheets of clear acetate film.)

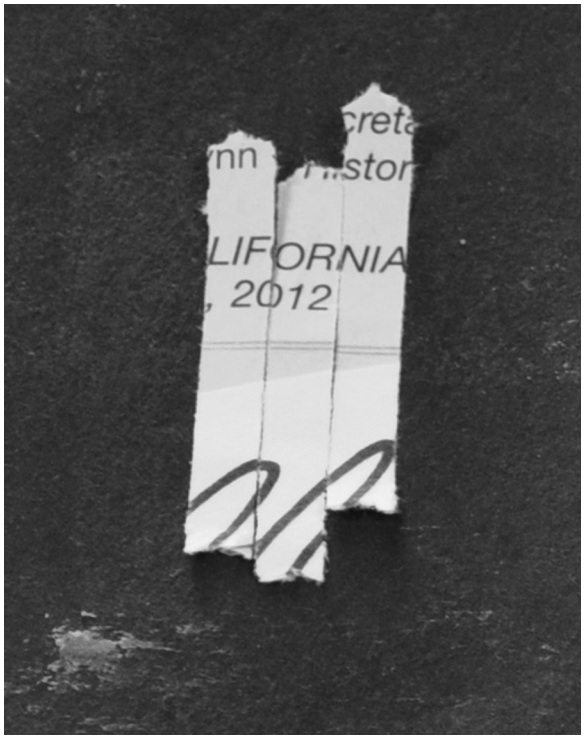

Figure 7. A cluster of shreds with a choice of reference lines to work from: either the double line ruling on the background document, or the border of the lighter note.

13c. On the back of the transparent substrate (e.g., document protector), draw the horizontal or vertical guide line, using a straightedge and fine point marker. Position it so there is enough room for the document to be assembled in all directions away from the reference line (Figure 8).

13d. Inside the document protector, begin to assemble the shreds at the reference line (Figure 9). In some manner, adhere the pieces to the substrate. A non-permanent method is recommended, in case false matches are made and the shreds need to be relocated (Osborn 1929, Harrison 1958, Kelly 2006). Consideration should be given to the adhesive used if the reassembled shreds are eventually going to be subjected to any further analysis. (For example, if an adhesive is applied to the side with ink writing, it may cause the ink to run.)

The author initially used a non-permanent glue stick applied directly to each piece. It may be applied to the back of the shred while it is laying on a firm surface, or the shred may be dragged across or pressed into the top of the glue stick (Figure 10).

Another method used was to apply the glue stick directly to the substrate surface, inside the document protector. This was effective when the shreds were from thin paper stock and were easily torn by the application of glue stick. (A disadvantage to this method is that the insides of the document protector would adhere to each other each time it was closed between applications of shred.)

An optimal method was suggested by a colleague who uses DryBond, a low-tack adhesive sheet by Chartpak for assembling shreds (Parker 2012). The author used this product first for associating shreds until ready for assembly, but he later found that if a shred is pressed against the sheet and then lifted, enough adhesive is removed to adhere the piece to the document protector.

14. Creating a grid of strip cut lines (the "alignment grid")

Prepare a grid of parallel lines spaced at the mean width of the shreds (the "strip cut" distance).

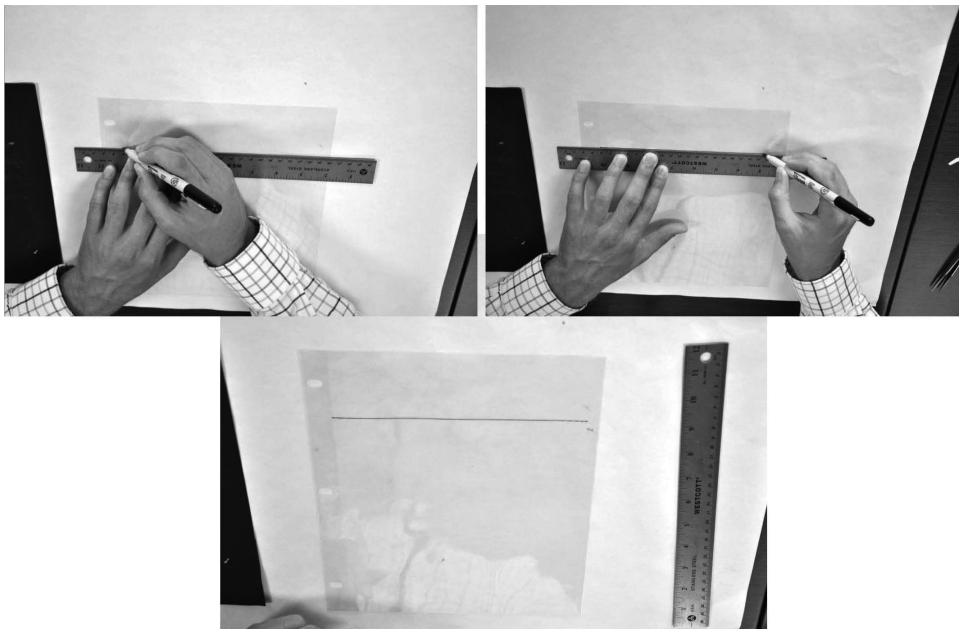

Figure 8. Drawing a horizontal reference line on the back of a document protector.

This is the strip cut or "alignment" grid, which can be used as a guide for assembling all of the documents shredded by the same shredder. It should be made as large as possible, to fit beneath documents of a variety of sizes. There are a few ways the grid could be produced:

a. On a transparent substrate using a fine point marker and straightedge, draw a grid of parallel lines spaced at the mean shred width. Parallel rulers or a rolling ruler used in drafting are well-suited for this task.
b. In a word processing program, prepare a table using the mean shred width as the line width (see Flynn 2006, for the method used to make a grid for measuring line spacing on machine-printed documents). Make the margins as narrow as possible, and print the table onto large sheets of paper or transparent film.
c. If the shred width was not measured previously, one can make a rough grid using the document being assembled. After several contiguous rows of shred have been assembled, turn the document over, and place another transparent substrate on top. Trace over the longitudinal cut lines with a straightedge and a fine point marker, drawing over as many cut lines as are assembled, then shifting the grid sideways to the last row but one, and tracing again. Continue until the sheet has been filled with parallel lines.

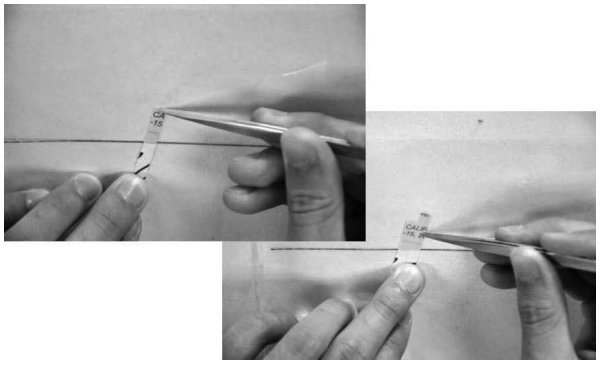

Figure 9. Attaching shreds to the inside of the document protector by aligning the Post-It™ note border to the reference line.

15. Position the alignment grid under the document being assembled to assist in aligning the assembled shreds (Figure 11). It may help to keep the grid and the document substrate paperclipped together.

16. Drawing the crosscut lines ("crosscut grid")

As additional pieces are associated, a zig zag pattern may begin to appear based on the position of the ends of the shreds.

Figure 10. Applying the adhesive lightly to the shred, or pressing the shred lightly into the top of the stick.

16a. One set of crosscuts will occur in every other row, and will appear to advance in one direction across the document (Figure 12a). On a separate piece of glass or plastic film or on the back of the substrate*, draw a line with a colored fine point marker to connect the centers of the ends of the assembled shreds thru one set of crosscuts. Project the line forward and backward (or up and down) onto every other row (Figure 12b). Additional lines can be drawn parallel to these spaced at the shred length throughout the document in both directions (Figure 12c). (*On Figures 12b through 12f, the lines have been drawn on the front of the document for illustration purposes. It is recommended that the lines be drawn on the reverse side instead, so they do not interfere with the image on the front.)

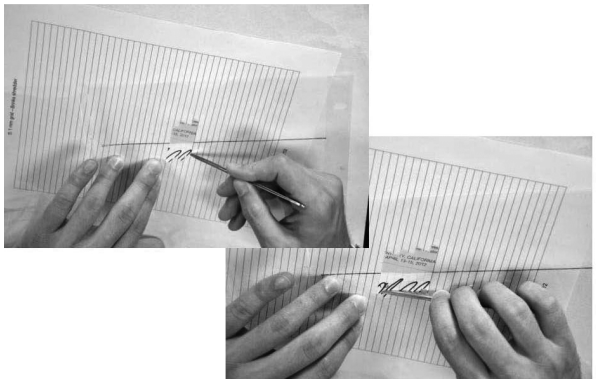

Figure 11. The alignment grid (printed from a word processing program) lies underneath the document being assembled.

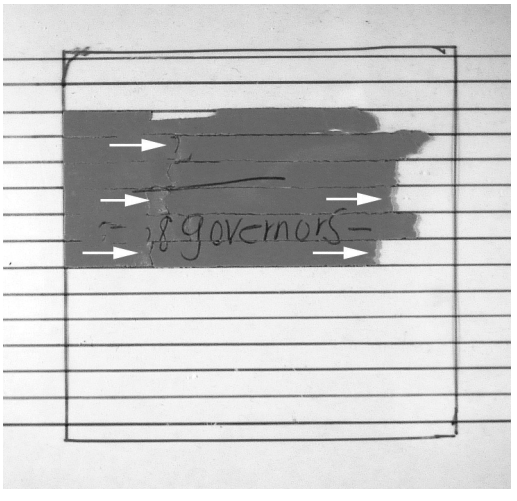

Figure 12a. Arrows indicate crosscuts in every other row. One arrow is missing in the upper right corner where the shred was torn rather than cut.

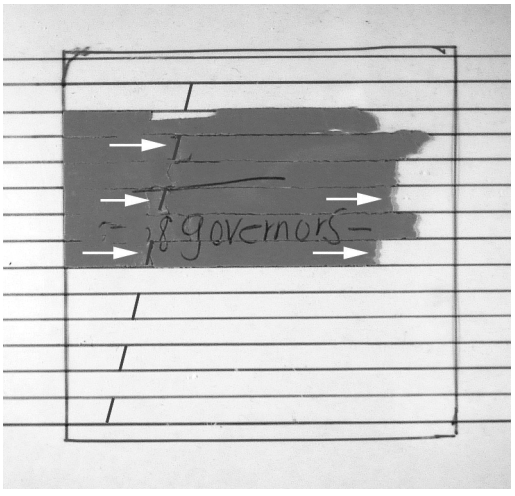

Figure 12b. A line drawn through the center of one set of cuts extrapolated in both directions.

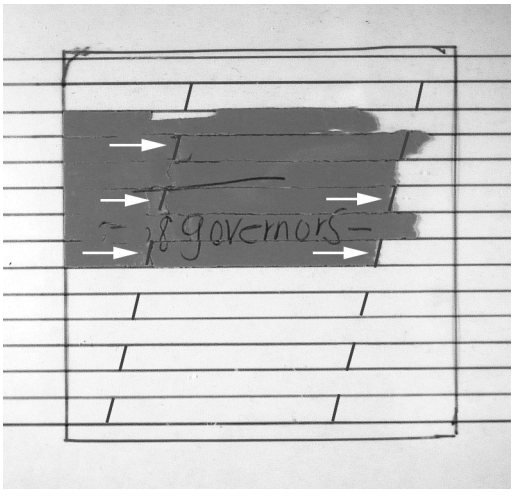

Figure 12c. A line drawn through the center of the cuts on the other end of the shreds.

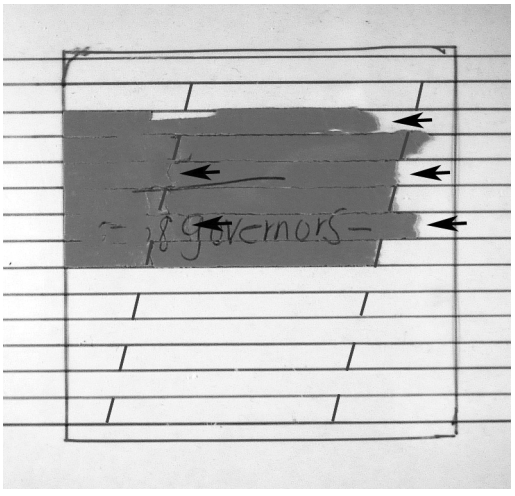

Figure 12d. Arrows indicate the crosscuts in every other adjacent row. One arrow is missing in the upper left corner where the shred was not cut.

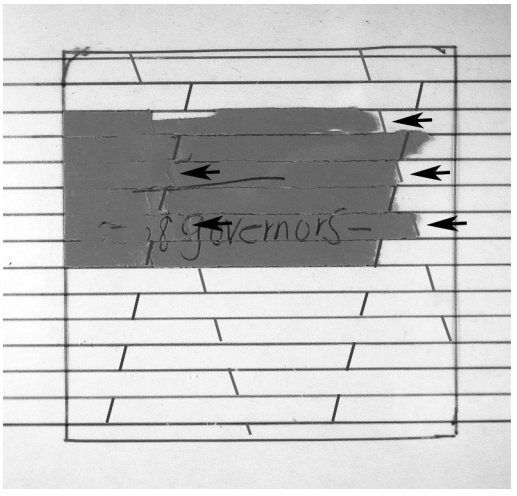

Figure 12e. Lines through the centers of both of the other set of cuts.

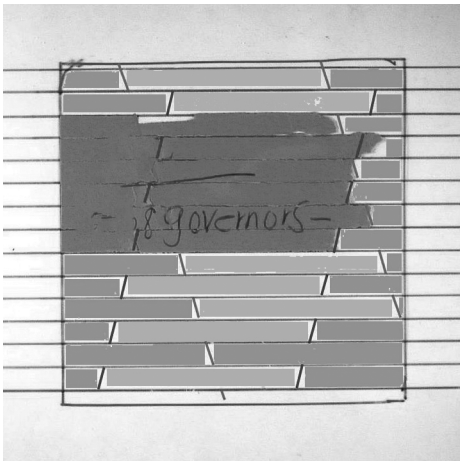

Figure 12f. The pattern into which the document was shredded. Missing are several internal pieces of the same size (the dark voids), and various sized border pieces (the lighter voids).

16b. Another set of crosscuts will occur in every other adjacent row (Figure 12d). Draw lines in a different color thru the center of these cuts as before and continue into adjoining alternate rows. The parallel lines can be extended to the borders of the document protector (Figure 12e).

With the alignment grid under the document, and the crosscut grid drawn in all directions, the resulting crosshatched diagram should approximate the pattern of pieces into which the document was shredded. The remaining shreds (which have been separated into edge and non-edge pieces, and arranged by size) can now be compared against the voids in the pattern to see where they might have originated, or whether they were part of this document at all (Figure 12f).

17. Continuing assembly until finished

Continue assembling the document from the remaining pieces within that subgroup. If the shred have been sorted and arranged using the steps above, the task of finding a piece of the right size, shape, and design to fit a void in the pattern should be easier. Assembly can continue either until the entire document is assembled, or at least until one is satisfied that all of the shreds bearing ink/printing have been incorporated.

If critical pieces of the image are missing, one may have to go back to the unsorted shreds or to those of another similar subgroup. Using the crosscut diagram should make it easier to fill in all of the voids in the document, especially those with no writing or printing.

Assembling documents with clones simultaneously

It was discovered to be much more difficult to assemble a document that was shredded sideways (horizontally) rather than longitudinally because of the white space between the printed or written entries on the document. Two documents in the author's case were shredded sideways at the same time, which created several packets of clones. The author's efforts to assemble portions of the documents, relate them all due to the clones, and stitch them together virtually using Adobe Photoshop will be the subject of a future paper.

18. Verifying assembly of the completed document

A fracture match examination of each cut edge is advised (which is easiest done during assembly, using a microscope and aided by lights and filters, if necessary) to be absolutely certain that the shreds originated from the same document (Hilton 1982, and Schuetzner and Commella 1997). This is especially necessary where pieces are reassembled that bear no writing or printing. This step may be time-consuming, but a necessary one to ensure the validity of the assembly opinion. Before making a conclusion as to the final appearance of the document, it is also recommended that another examiner verify the image of the completed reassembly.

19. Recording the document's final appearance

The appearance of the assembled document on both sides should be recorded. In the author's case, once a document was completed, a 300 dpi color image of each side (with scale attached) was created using a scanner. Although typical laboratory practice is to work a case to completion before sending a report, in this case, a report and corresponding images were sent to the submitter each time a couple of documents were finished, to provide additional information for the investigation.

20. Disposition of the evidence

At some point, the examiner and/or the submitter will determine that enough has been accomplished. The assembled documents can be sealed or encapsulated for protection during their return to the submitter. Any remaining shreds can be packaged and returned. In the author's case, sorted, but unused pieces were placed in the pockets of a plastic baseball card protector and labeled as they were sorted in their subgroups (Figure 13).

Outcome

In the author's case, twenty-one documents were eventually reassembled. The first completed were five pink and three blue Post-it™ notes, and one blank fax cover sheet with handwritten notes

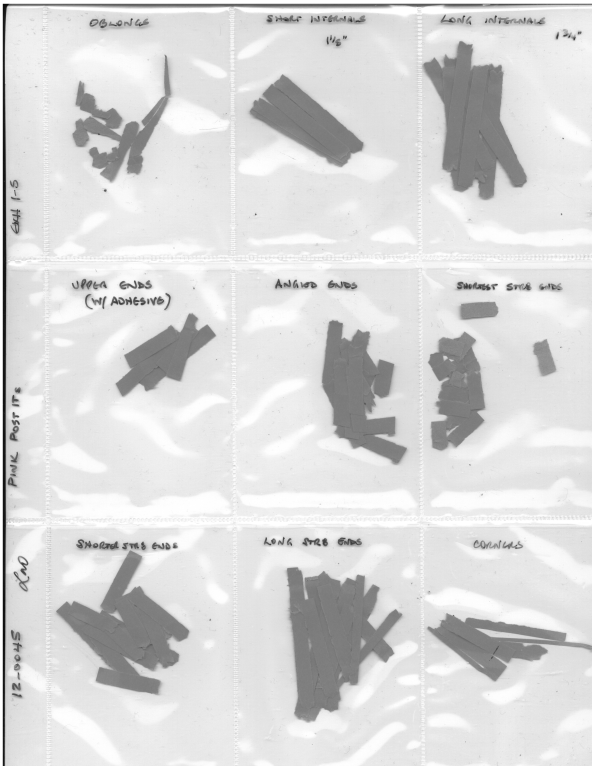

Figure 13. Unused pink Post-It™ shreds separated by size and shape.

on the back. The most important documents, however, proved to be twelve sheets of ruled paper of white and yellow, bearing lists of names, Social Security Numbers, and birthdates of persons whose identities had been stolen for the filing of false tax returns.

Summary

This methodology enabled the reassembly of an assortment of crosscut shredded documents. By sorting and arranging the shred by various characteristics, making some rudimentary measurements, and illustrating the pattern formed by the strip cuts and the crosscuts, the author was able to predict where the voids were and locate the pieces to fill them.

Although used here in an "ideal" case (with a relatively small sample of crosscut shredded documents), the methodology offers techniques which can facilitate the manual reassembly of any crosscut shredded documents.

Acknowledgements

The author would like to thank several people for their assistance in completing this work:

- co-workers at the at the IRS National Forensic Lab (Robin Hunton, Jean Dietrich, Jody Rhodea, Mary Fitzgerald, Judy Gustafson, Paula Henderson, Alisa Skinner) who helped sort and associate shreds in the early stages of the case; acted as guinea pigs in testing the methods for a workshop; and provided assistance with this paper;
- Barbara Torres of Los Angeles County Sheriff's Department, Timothy Cheadle of Los Angeles Police Department, and Brett Bishop of the Washington State Patrol Lab, who provided feedback on an early version of this paper;
- Linda Mitchell from Alliance Forensic Services, Escondido, California, who presented this talk for the author at the 2012 ASQDE meeting and made several useful improvements;
- persons who provided feedback or materials used by their labs to reassemble shredded documents (Diana Harrison and Ted Burkes of the FBI, Joseph Parker and Derek Hammond of the US Army CIL, and Samiah Ibrahim and Andrew Barton of the Canada Border Services Agency);
- representatives from the shredder industry: David Hartnett and Vadim Romanovich at Fellowes Incorporated, Itasca, Illinois; and Jim Parkinson, Greg German, Peter Dempsey, Paul Wildey, and Tyler Bear at Martin Yale Industries, Wabash, Indiana (manufacturer of Intimus shredders), who provided technical assistance about their products and shredders in general; and
- Matthew McDonald, a senior from University of Wisconsin-Platteville, who completed an internship with the author to examine class characteristics of seven shedders.

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