A comparison table is completed for all of the known exemplars and also separately for the questioned document. At the end of the process, the examiner has a set of tables – one set providing a comprehensive log of photographic images of the known variants of a specific person’s handwriting and another set of tables with the variants found solely in the questioned document. The examiner then compares the results found in the two sets of tables to look for similarities and differences. The goal is to achieve a very high probability of either matching the two documents or showing that they were produced by different hands. As a last step, the examiner prepares a final comparison table, such as that shown in Figure 17.1.11, that combines the results of the individual comparison tables to highlight the differences and similarities found between the exemplars and the questioned document. The example in Figure 17.1.11 shows that there is a very high probability that the two documents were indeed written by the same person.

Simulation, intentionally disguising one’s handwriting such as in creating a forgery or in providing a requested exemplar, may be difficult to discern although there are a number of telltale features that can be used to help detect when it occurs. Ideally, the documents to be compared should be as long as possible to provide a meaningful sample of variants. This is also important because, while someone may be able to disguise their writing for a short while, they eventually get careless, tired, or forgetful and revert back to their native handwriting styles. Finding significant differences, especially noting stylistic differences between the beginning and the end of the document, can be an important indicator of simulation. Other indicators of simulation include shaky lines, irregular starts and stops in the writing, uneven or heavy pressure on the paper, slow writing, and inconsistent or oddly changing letter characteristics.

**Questioned Signatures**

Among all forms of handwriting, a person’s signature is the most personalized and sometimes the most valuable. We use our signatures to certify our wishes, transfer funds, make agreements, and validate legal documents. Because of the value of signatures as our endorsement of a document, forensic questioned document examiners are often required to determine if a signature is authentic or a forgery. Generally, analysts look specifically at the accuracy and fluency of a signature in determining its authenticity. The accuracy of a signature relates to how the letters are formed, including any embellishments, and whether it contains individual characteristics that match with the exemplars. Fluency relates to how smoothly and rapidly a signature is made. People often spend years “working” on their signatures to individualize them, and, therefore, can generate sometime intricate signatures quite rapidly. Accuracy and fluency in a forgery actually work against each other – as a forger writes more fluently (rapidly), the accuracy of the signature is usually decreased. In the analysis, it is usually not possible to determine specifically who the forger was but rather only whether the signature was (or was not) forged. A famous example is shown in Figure 17.1.12.

![Figure 17.1.12. Questioned signature of famous baseball player Mickey Mantle on a photograph. Mantle’s known signature is shown at top and the lower two were determined by the FBI to be forged versions](http://science.howstuffworks.com/handwriting-analysis1.htm)
example, shown in Figure 17.1.12, illustrates a comparison between an exemplar and two questioned signatures that the FBI determined to be forgeries. The position of the signature relative to the rest of the document can also be important if a recognized trend in where someone characteristically signs is known, such as illustrated in figure 17.1.13 for President Harry S. Truman.

There are several common methods that forgers use to produce unauthorized signatures and handwriting. These include:

- **Forged signature**: In this case, the forger makes no attempt to conceal their own handwriting and simply signs a person’s name to a document using the forger’s normal handwriting. This is more effective than might be thought since the recipient of the forgery might have no ready frame of reference to even suspect a forgery.

- **Simulated signature**: These are signatures where a forger first examines carefully an authentic signature and then produces the forgery “freehand”, without any aid except the forger’s skill. The forger may first practice repeatedly to become proficient in producing the signature naturally before making the actual forgery.

- **Traced forgery**: The forger uses an authentic signature as a template that they carefully follow in making the forgery. There are several ways that this can be done. In one method, the forger places the authentic signature over the document that will contain the final forgery. They then trace heavily over the authentic signature, making an indented version of the signature on the forged underlying document. Finally, the forger goes over the indentations on the forged document with a pen to produce the final signature. In another method, the document containing

**Figure 17.1.13.** The placement of a person’s signature can also indicate a forger’s work. For example, in David Owens’ book Hidden Evidence the position of President Truman’s signature relative to the text of a document was important: “President Harry S. Truman invariably placed his signature on typed documents close to the last lines of the text, as shown in the top and center examples. [T]he forgery at the bottom is clearly too far from the text” (Owen, David. Hidden Evidence: 50 true crimes and how forensic science helped solve them. Second revised edition. Pg. 150, 2009).

Detection of a Forgery

Forgeries often show some telltale features that analysts look for in their analysis, such as:

- Shaky handwriting;
- Unusual pen lifts from the paper;
- Slow writing;
- Retouching attempts (after the writing has been done to make it look better);
- Resting points (small “dots” where the pen has rested on the paper when interrupted during making a forgery);
- Indentation (evidence of a tracing);
- Underlying pencil marks (evidence of a tracing);
- Exact match between questioned signature and an exemplar (evidence of tracing since it does not show any natural variation);
- Scaling differences (unusual relative dimensions of the letters and words resulting from a lack of fluency in the writing).
the authentic signature is placed under the document that will contain the final forgery. A light is then shone through both documents from below (often using a light-box or window) and the forger follows the authentic signature in pen on the top forged document. In a third method, a pencil version of the authentic signature is first carefully made, either freehand or by using carbon paper. Then, the forger traces directly over the penciled signature in ink. After the ink has dried, the pencil marks can be erased, leaving just the pen signature visible. Each of these methods, however, leaves behind remnants of the tracing method that can be observed through microscopic or spectroscopic study.

- **Intentional forgery**: In this case, a person intentionally adds forced or unusual features into their own signature such that they can disclaim the signature later.

- **Fictitious signature**: In some instances, both the document and the signer are fictitious such that there are no exemplars and the signature cannot readily be compared with others samples. This might be the case when someone uses an alias or when they try to use an official document with an untraceable name to identification or other purposes.

- **Cut-and-paste**: Using computer or photo-copying technologies, an authentic signature may be copied from one document and pasted into the forged one. Microscopic examination can often detect this type of forgery.

There are a number of difficulties, however, in analyzing a signature. Since signatures are relatively short and often embellished, they often do not display the range of natural variation in a person’s handwriting. People never sign their names in exactly the same way twice, further complicating the analysis. For example, if you sign your name multiple times on a single piece of paper and then examine them, you will find clear differences that distinguish each one from all of the others. These factors mean that a significant number of signature exemplars are needed to make the comparison valid. Finally, it is important to remember that legally a forgery requires the intent to defraud or mislead – it is not a forgery to sign for someone with their full approval and knowledge.

**Printed Documents**

Today, many people spend far more

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*Figure 17.1.14*. The parts of a traditional manual typewriter. The parts are the: (1) keys, (2) level, (3) type hammer, (4) ink ribbon, (5) paper, (6) ribbon cartridge, and (7) carriage return lever (www.explainthatstuff.com/typewriter.html).

*Figure 17.1.15*. Typewriter ball used for transferring images of letters to the paper through an inked ribbon (http://hellotypewriter.tumblr.com/post/472213423/really-really-really-want-one-of-these-ibm-golf).
time typing their communications than using handwriting on paper. In some ways this makes determining the authenticity of authorship of a document more difficult, but not impossible. It should be noted that determining the authenticity and possibly the source of a typed or printed document is quite different from the field of cybersecurity – verifying computer based information and communications – that will be presented in the following chapter.

**Typewriter forensics:** Typewriters are rapidly becoming obsolete and far less commonly encountered in forensic applications. Nonetheless, typewriters are still used in a significant number of homes and offices for producing many types of documents. The forensic identification provided by matching a typed document with a specific typewriter has been well established. Typical questions posed to examiners are what type of typewriter or printer produced a given document (manufacturer, make and model) and whether a specific machine was used to produce a questioned document.

Typewriters work by manually depressing a key that moves a lever with a raised template (a die) of the letter on its end (called the hammer). The typeface die strikes the paper by hitting an inked ribbon that transfers an ink image of the letter to the paper (Figure 17.1.14). Typewriters can be either electric or manual versions and most commonly use either a one lever-die combination per letter (including a printwheel) or a “ball” that contains all the letters (Figure 17.1.15). Manual typewriters (non-electric) usually have one permanent typeface that cannot be changed readily while electric units often have interchangeable typeface balls that allow changing fonts. A font is a complete set of type in one size and design, such as shown in Figure 17.1.16 or a few common fonts. Today, there are thousands of fonts available for computer-based printing.
but both manual and electric typewriters are typically limited to just a few possibilities. The size of a font is usually given in points, which dates back to the beginning of printing, and today is defined as 72 points per inch (or 1 point is equal to $\frac{1}{72}$ inch and 12 points make up the unit called a pica), as illustrated in Figure 17.1.17. To define a particular sample of printing, including typewriting, the class characteristics of font, size, style (e.g., italics, bold, all-capitols, etc.), ribbon-type, and color are all determined. In the case of a typewriter, as the machine is used, the letter typefaces gradually become worn, dirty, miss-aligned, and even damaged by miss-hits. These imperfections are the source of individual characteristics of a specific typewriter that may connect a sample of writing with an individual machine. For example, in Figure 17.1.18, a damaged and worn typeface produces a uniquely modified typed letter. In addition, when the typeface strikes the inked ribbon and transfers the ink to the paper, the ink where the letter strikes is removed from the ribbon. Sometimes, the cloth or paper fibers that make up the ribbon can be seen microscopically in the final typed letter and matched to the ribbon, such as shown in Figure 17.1.19 and 17.1.20. Additionally, most typewriters mechanically move the ribbon forward slightly after each letter is struck so that each letter has a fresh ribbon surface to make the print. This means that the ribbon is a type of “ticker-tape” that can be examined to read back the letters and words that were types on that particular typewriter, such as shown in Figure 17.1.21.

**Printer forensics:** Computer-based printing has enormously reduced the use of typewriters in preparing a document. In these systems, the document is first prepared, edited and stored on the computer, with an enormous range of possible fonts, styles, spacings, sizes, and graphics...
readily available to the typist. Once prepared, the document may be printed out as many times as desired using one of three main types of computer printers. A dot-matrix printer is most similar to a typewriter in that a dot-matrix printer uses an inked ribbon that is struck to produce the images on the paper. Dot-matrix printers, rather than using a single die for each letter, instead use a series of very tiny pins that combine to form the image of a letter on the paper (Figure 17.1.22). This is the oldest computer printer technology and is largely being replaced by the other printer types. An ink-jet printer forces ink through a nozzle to form the letters on the page. Finally, in a laser printer, a laser beam (intense beam of light) is used to form a positively charged image of what is to be printed on a rotating metal drum (Figure 17.1.23). Then, a negatively charged toner powder (the “ink”) is adhered to the drum only where the positively charged image has been formed. The resulting toner image is then rotated and transferred onto the paper and fused to the surface by the application of heat.

In the examination of printed documents, it is often very difficult to discern information beyond what class or type of printer was used and possibly what software program was employed to create the text (not all fonts are available to different software packages). It is very difficult to identify an individual printer from the documents it prints. In some instances with laser printers, however, it is possible to identify unique imperfections located on the image drum that can then be transferred to the paper. Identifying these imperfections may, in rare instances, provide a method of identifying a single laser printer as the source of a questioned document.

Photocopiers: Photocopiers are very common, readily available to almost everyone, and provide
for the rapid duplication of documents, sometimes with extraordinary levels of replication. A typical photocopier operates on essentially the same principles of a laser printer (Figure 17.1.23) and employs a rotating drum, an intense light source, and a toner powder to create an image. Because of wear and microscopic damage to the rotating drum through heavy use, it is sometime possible to connect a particular photocopied document to one machine by matching these characteristic imperfections on the drum with the corresponding imperfections in the print. Usually, this requires a microscopic examination of the document and a series of test print exemplars from the photocopier in question to compare. Additionally, the chemical analysis of the toner, presence of any marks from the paper handling machinery of the copier, and dirt and scratches on the window (seen as small specks, called trash marks, on the photocopy) help to individualize a particular printer. The trash marks may be particularly useful in quickly linking together a group of documents as produced on the same machine.

**Printed Documents:** The detection of forged printed documents, most often counterfeit currencies, bonds and similar valuable items, is an area of enormous concern worldwide. To try to combat counterfeit money and certificate production, governments and corporations continue to develop both traditional and new high-technology measures for detecting...

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**Figure 17.1.24.** Some of the anti-counterfeit measures used to thwart and detect counterfeit currency (www.jcheights.com/news.shtml).

**Figure 17.1.25.** A anti-counterfeit strip embedded in the paper of a US $20 bill that fluoresces under UV light (en.wikipedia.org/wiki/File:US_$20_under_blacklight.jpg).

**Figure 17.1.26.** A comparison microscope examination of an authentic (left) and a counterfeit bill (right) shows the proper alignment at the top and a miss-alignment of the printing at the bottom of the note (www.leica-microsystems.com/fileadmin/.../forensic_brochure_part2.pdf).
and thwarting the counterfeiter’s work (Figure 17.1.24). Unfortunately, this is a continuing battle as counterfeiters continue to use increasingly sophisticated reproduction methods. Some of the more common anti-counterfeiting measures currently in use include special inks and papers, raised printing, watermarks, micro-printing, embedded identification strips (Figure 17.1.25), designs that are difficult to reproduce or photocopy, holographic images, color/image shifting printing, and serial numbers, among many others (Figure 17.1.26). A watermark is a translucent design that is pressed or otherwise ingrained into the paper when it is manufactured to leave a faintly visible image when held up to a light source. For example, if most forms of modern currency are held up to the light a faint image will be seen that was invisible before (Figure 17.1.27). Manufacturers of paper for both commercial and private use also often employ watermarks and frequently change aspects of their own manufacturer’s watermark or employ special watermarks designed specifically for one customer so that they can sometimes be used to establish the date (or range of dates), manufacturer, and purchaser of the original paper. Of course, missing watermarks where they would be expected also can readily expose a counterfeit document. Examiners usually also determine the method used in producing the printed item (e.g., silk-screening, lithography, and others).

A key method for analyzing counterfeit currency is the comparison microscope. For example, an authentic and a questioned bill can be easily compared such as illustrated in Figure 17.1.26. Other analytical methods will be discussed in a following section.

Figure 17.1.27. Many methods are used to help prevent the production of counterfeit bills. Micro-printing (Top left) on a $50 Bill shows the words “The United States of America” printed on Pres. Grant’s collar, and (top right) shows very fine printing at the edges of $5 and $10 bills. Special paper (bottom left) is used that contains very fine blue and red fibers embedded in the paper (not printed on the surface of the bill). Watermarks, such as the image of Alexander Hamilton on the $10 bill (bottom left), show the image of Hamilton when held up to the light (www.cnbc.com/id/3598340/Combating.Counterfeiters_Defense_is_in_the_Details).
Obliterated, Altered, Erased and Indented Writing

Criminals may desire to alter or somehow change existing documents to modify or obliterate their original meanings. For example, the simple addition or deletion of a single zero at the right of a number changes its value ten-fold. This single action can quickly change a $100 check into a $1,000 check or an IOU from $10,000 to $1,000. Questioned document analysis includes methods that try to restore the original writing in these cases to their intended meaning and intent.

Obliterated writing occurs when someone tries to conceal original text by adding an opaque substance to block out the ability to visibly read a portion of the document. Techniques have been developed, however, that often allow the original writing to be visualized. These techniques range from simply shining light through the document from behind to the use of high-tech alternative light sources and spectroscopic methods. For example, ultraviolet or infrared light sources can resolve the ink from writings from the substances used to obliterate the writing, such as shown in Figures 17.1.28 and 17.1.29.

Altered writing, including erasures, additions and deletions, can dramatically change the meaning of a text. If the altered writing has been done by adding writing to the document from a different pen, the chemical differences between the two inks can be spectroscopically differentiated to show what was the original and what was the added text (Figure 17.1.30). Erasures can also been made visible by using alternative light sources to highlight minute traces of the ink or pencil marks that remain from the original writing.
When writing on a piece of paper that lies on top of other sheets, the pressure of writing can cause indentations on the lower pages, called **indented writing** (or sometimes second page writing). These faint indentations form an accurate record of what was written after the top document is removed (Figure 17.1.31). Indented writing often happens when writing on pads, diaries, official files (part of a stack of papers), and desk blotters. Matching indented writing in paper in a suspect’s possession with that found at a crime scene provides an immensely valuable link between the suspect and the crime. Similarly, when indented writing does **not** agree with what appears on the written document then an alteration has most likely been made to the original document.

A number of methods have been developed to visualize indented writing, including oblique lighting (Chapter 16.3) and using an electrostatic detection apparatus (ESDA). Oblique lighting, light that comes in at a low (or oblique) angle relative to the surface of the document, highlights any minute depressions in the paper by causing shadows to form in the indentations. This technique works well for fairly deeply indented paper but may miss more subtle or faint indentations.

Probably the most common method for visualizing indented writing uses an electrostatic detection apparatus (ESDA). In this method, a plastic (Mylar) film is firmly adhered to the surface of the document using a vacuum (Figure 17.1.32). The paper/Mylar combination is then treated with a high voltage electrostatic charge. This process yields a charged surface on the plastic with the greatest charge accumulating where the paper has been indented, locating even very faint, microscopic impressions. Toner powder is then spread over the charged plastic surface and the toner is most
strongly attracted to the highest static charged areas – areas that contain the indentations. After the excess
toner has been removed, the visualized indented writing may be either photographed or preserved by
placing a second adhesive plastic layer on top of the Mylar – effectively making a “sandwich” containing
the toner highlighted writing. ESDA methods are very sensitive, often revealing writings missed by other
methods. Importantly, the untouched original document may be recovered after the ESDA has been used
to visualize the indented writing.

Analytical methods
In the analysis of questioned documents, key information can come from the chemical and
physical analysis of the paper and inks used in the preparation of the document. From these analyses, the
type, age, composition, and even the origin of the ink and paper may be sometimes determined. For
example, finding that the ink on a document had a component that was not available when the document
was supposedly written rules out the ink or paper as original (see “Hitler Diaries” inset box).

Ancient Words Restored
Sometimes, restoring obliterated writing can have non-legal but yet very important uses. For
example, probably the most famous mathematician of all time was Archimedes who lived in ancient
Syracuse from about 287 to 212 BCE. Probably his greatest achievement and life’s work, however, was
lost - called the Archimedes Palimpsest. In the 12th century, the text was scraped from the parchment
pages, turned 90°, folded and overwritten with the text of a book of prayers. The manuscript was shortly
thereafter lost to history – or so it was thought until 1906. In that year, a Danish scholar recognized the
manuscript during his travels and was able to photograph and discern some of the Archimedian text
before it was once again lost. Then, in 1998 it resurfaced, was purchased by an unknown buyer and the
restoration work began in earnest. Using a variety of light sources, including light from the Stanford
Linear Accelerator, the original writings have now been restored. But there was an added bonus. Not
only did the Palimpsest contain five complete works of Archimedes, including the only known copies of
three of these, but it also contained 4th century speeches by Hypereides, Aristotle’s Categories transcribed
by 3rd century philosopher Alexander of Aphrodisias, and other works.
Inks are analyzed in a variety of ways, including some methods already described in this chapter. One of the most common methods involves the chromatographic separation of the different chemical components in the ink (See Chapter 11.3 for details on Chromatography). In summary, chromatography uses the varying interactions of different chemical compounds towards a common material, such as paper or silica gel. For example, compounds that only weakly interact with the paper can be pushed along by the movement of a solvent through the paper rather easily. Compounds that interact more strongly with the paper, however, move more slowly. Different inks can be readily separated and analyzed from one another using such chromatographic techniques. Different colored inks are almost always made up of a number of compounds. For example, blue ink often contains blue, red, purple, magenta and other colors mixed together in differing proportions to give the characteristic hue of the ink. Separating and analyzing the chemical composition and relative amount of each pigment in the ink can be used to identify the specific ink used in preparing a document (Figure 17.1.33).

One method becoming increasingly common for examining altered writing is called **hyperspectral imaging**. This type of imaging gathers light from a wide band of the electromagnetic spectrum, typically the visible and near infrared part of the EM spectrum, and breaks it into smaller bands for processing – each band covering a relatively small portion of the spectrum. Each pixel (very tiny part of an image) of the digitized document is analyzed for the amount of light absorbed or reflected at the wavelengths in the band. When the bands for each pixel are analyzed, differences in the chemical compositions in different locations of the document can be observed, such as the locating two different types of ink in various places on a questioned document (Figures 17.1.34 and 17.1.35). Similarly, hyperspectral imaging can readily detect the alteration in a document, such as the addition of a small...
mark in Figure 17.1.34 to convert the numeral “0” into a “9”.

**A Master Forger’s Work**

One of the most famous and gifted of forgers was Joseph Cosey who did his work during the early part of the 20\textsuperscript{th} century. Cosey specialized in historical documents, from Jefferson to Lincoln. One of the reasons that Cosey’s work was so hard to detect was that he used “vintage” materials – paper, pens, and inks that were used at the time that the forged authors lived. Combining these period materials with an amazing skill, Cosey was very successful in his trade – but not quite successful enough. He was eventually caught in 1937 and sentenced to three years in prison. It is believed by experts that many of Cosey’s forged documents are still in circulation and believed to be authentic.

For example, one of Cosey’s most famous forgeries was the signature of President Abraham Lincoln (below). The top signature is the forgery and the bottom is the actual signature of Pres. Lincoln. Note that the forgery follows a rather straight line while the original is much more irregular in its baseline. Nonetheless, it is an amazingly good replica.

![Signature](image)

A variety of other spectroscopic methods have been used in analyzing inks and papers. These have included Raman spectroscopy, infrared spectroscopy, mass spectrometry, and others. Each provides specific advantages depending upon what information is required (see Chapter 12).

The writing on burned and charred documents can sometimes be visualized using spectroscopic methods. The chemical analysis of paper may also provide clues as to its components, type, manufacture, and origin. As with other types of physical evidence, pieces of a torn or ripped piece of paper can be fitted back together to show that they were once one single piece (Figure 17.1.36)

**Legal Challenges to Handwriting Analysis**

In recent years, strong challenges have been made in the courts as to the scientific basis and reliability of forensic questioned document analysis, especially handwriting analysis. While a number of Supreme Court rulings have upheld the place of handwriting analysis in forensic settings, controversy still remains around its use in cases and, at this point, the courts are divided as to its admissibility. There have been an increasing number of cases where forensic handwriting analysis has been successfully challenged on the grounds that it does not meet the Daubert requirements for good scientific analysis. In an important recent case (*United States v. Saelee*, 2001), the District Court ruled that handwriting analysis was based on a “lack of empirical evidence on the proficiency of document examiners” and “little empirical testing [had been] done on the basic theories upon which the field is based.” Additionally, the court found that “not much is known about the error rates of forensic document examiners.” Because of
this, they ruled that in this case “the handwriting expert’s testimony [was] not sufficiently reliable to be admissible.” Other court decisions, however, have found handwriting analysis meets acceptable scientific standards and is admissible. In a recent 2011 study, the handwriting of 1,500 people was analyzed by a computer program and found that the program was “able to establish with a 98 percent confidence that the writer can be identified.” This result, when considering the age, race, sex and other variables of the writers, was extrapolated to conclude that the estimated confidence of determining the writer of a document for the entire US population was 95%. Nonetheless, handwriting analysis is still employed in forensic investigations and important work is now being done to provide the necessary validation and quantification to allow this form of analysis to stand firmly on a solid scientific foundation.

2001 Anthrax Attack

In September 2001, anonymous letters containing deadly anthrax spores were sent to several news agencies and Congress. Ultimately, five people were killed and 17 others infected. The government launched one of the most extensive and far reaching criminal investigations ever taken to find and stop the perpetrator.

One of the key pieces of evidence came from the actual letters containing the spores (see below). All the letters were prepared on a photocopy machine and were different sizes. The letters were carefully analyzed for handwriting, syntax, and hidden meaning to provide important clues in the case. Eventually, the letter evidence and other investigative information, such as analyses of the anthrax origins, led the FBI to conclude in 2008 that a former biodefense worker, Bruce Ivins, was the sole perpetrator of the crime. Ivins committed suicide on July 27th, 2008 and the FBI formally closed the investigation in 2010.