NIST Technical Note 2190

NIST Special Database 302

Supplemental Release of Latent Annotations

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Abstract

The National Institute of Standards and Technology (NIST) released a collection of latent fingerprint images as part of Special Database (SD) 302 in December 2019. While the dataset included 10 000 never-before-seen operational quality images from 200 study participants, SD 302 has been of somewhat limited usability, in part due to the omission of study participant finger position ground truth. To help make SD 302 as robust and useful to the community as possible, NIST has funded certified latent print examiners to annotate and determine the source of the latent fingerprint images distributed as part of SD 302.

Key words

biometrics; data; extended feature set; fingerprints; images; latent.

Human Subjects Research

The National Institute of Standards and Technology Institutional Review Board reviewed and approved the protocol for this project and all study participants provided informed consent.

Acknowledgments

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1. Introduction

The National Institute of Standards and Technology (NIST) released 10 000 latent fingerprint images from 200 study participants as part of Special Database (SD) 302 in December 2019 [1]. The latent fingerprint images originated from a September 2017 data collection sponsored by the Intelligence Advanced Research Projects Activity (IARPA) as part of the *Nail to Nail (N2N) Fingerprint Challenge* [2]. Study participants were asked to perform a variety of routine activities, including handling paper currency, using a mobile phone, and writing a grocery list. Certified latent print examiners (CLPEs) processed items handled by study participants and imaged friction ridge impressions present. Each item was labeled with the study participant's identifier to maintain a chain of ground truth. Extensive detail regarding substrates, simulated movements, collection, development, post-processing, and more can be found in Section 5 of *NIST Interagency Report 8210* [3].

Despite the large number of never-before-seen operational quality latent fingerprints images, SD 302 has been of somewhat limited usability. For one, because study participants were not instructed—and more importantly, not expected—to handle materials uniformly, it was not possible to readily ascertain the ground truth *finger position* for each latent mark. SD 302 identified only the study participant, and in limited cases, the hand, but *not* the finger from the hand. Additionally, minutiae present in the latent fingerprint images were not marked. CLPE-marked minutiae have been shown to be critical to the success of automated latent friction ridge identification algorithms, as opposed to image-only searches [4, 5]. CLPE-marked minutiae and finger position information were available in NIST's previous widely-used latent datasets (e.g., SD 27), however these datasets are no longer available for distribution.

To help make SD 302 as robust and useful to the community as possible, NIST has funded CLPEs to annotate sets of latent and exemplar fingerprint images distributed as part of SD 302. Images from the first 119 study participants have been released as of this publication date in November 2021. The remainder will be continuously released in waves as funding allows.

The supplemental annotation datasets are referred to as SD 302g–i:

- **SD 302g**: Annotated exemplar images,
- **SD 302h**: Annotated latent distal phalanx images, and
- **SD 302i**: Minutiae correspondence between SD 302g and SD 302h.

Six datasets previously existed in the SD 302 release series:

- **SD 302a**: Challenger rolled-equivalent friction ridge images,
- **SD 302b**: Baseline operator-assisted rolled fingerprint impressions and 4-4-2 slap impressions,
- **SD 302c**: Palm images and fingerprint images segmented from upper palms,
- **SD 302d**: Plain fingerprint images from auxiliary devices,
- **SD 302e**: Latent distal phalanx images, and
- **SD 302f**: Unprocessed photographs from Challenger T's prototype device.

2. Tasking

SD 302 contains 50 latent distal phalanx fingerprints per study participant, for a total of 10 000 images. Individual latent fingerprints were cropped from full-scene captures, such as an image of the entirety of a developed piece of paper currency or a scan of a complete piece of tape from a black powder lift. SD 302 also contains several sets of rolled contact exemplar fingerprints for each study participant (e.g., from N2N Challenger devices), including two sets captured by representatives from the Federal Bureau of Investigation (FBI). These new supplements to SD 302, named SD 302g–i, extend this data by providing fingerprint annotations from CLPE and expanding available ground truth information.

2.1 Requirements

NIST researchers used services from CLPEs to perform the necessary annotation activities. These trained professionals were asked to:

- annotate a set of FBI-rolled fingerprints to Extended Feature Set (EFS) Profile 2 [6],
- annotate all latent images to EFS Profile 2, placing features without the assistance of feature auto-encoding algorithms,
- determine ground truth finger position, and
- link sufficient corresponding minutiae from latent to exemplar.

2.1.1 Extended Feature Set Profile 2

EFS is a set of common latent fingerprint features specified in *NIST Special Publication 500-290* [7]. Subsets of these features, known as *profiles*, have been defined for common search scenarios, to allow for trade-offs between examiner time and search accuracy [6]. EFS Profile 2 is known as *Quick Minutiae Search* and is a very common subset of features supported by many Automated Fingerprint Identification Software (AFIS) vendors. The following features with their corresponding EFS field number are included in Profile 2 and were populated by CLPEs in the new SD 302 supplemental distributions:

- `9.300`: Region of interest
  - Provided by NIST for latents, and defined as the entire image area for exemplars.
- `9.301`: Orientation
  - Provided by NIST for exemplars only.
- `9.302`: Friction ridge position
  - Provided by NIST for exemplars only.
- `9.307`: Pattern classification
- `9.320`: Core(s), if present
- `9.321`: Delta(s), if present
- `9.331`: Minutiae, if present
- `9.354`: Evidence of fraud
  - Omitted, since all study participants willingly participated.
- `9.314`: Tonal reversal (complete)

2.1.2 Supplemental Exemplars

Initially, the rolled fingerprints provided to CLPEs for annotation were all collected with the same physical device, an HID Crossmatch L Scan 1000PX[1], referred to as the *baseline* exemplar set. This project has been in progress over several years. After images from the first several study participants were annotated, the CLPEs discovered that the baseline exemplar set was often not sufficient to make a proper source determination, but other exemplar fingerprints provided in SD 302 were sufficient. To this end, NIST asked the CLPEs to annotate all additional exemplars used to make a finger position source determination if a latent fingerprint could not be sourced to a rolled exemplar from the baseline exemplar set. This way, SD 302 would still gain a complete set of rolled exemplar prints collected on the same hardware, and minutiae correspondence could still be recorded.

[1]Device `V` from SD 302.

2.2 Minutiae Correspondence

Minutiae correspondence refers to the one-to-one mapping of minutiae from a latent fingerprint image to an exemplar fingerprint image. Accurate minutiae correspondence is easier for CLPEs when the ground truth source finger is known. This type of information has usefulness in the research community in terms of validating algorithm outputs, development of statistical models, and more.

3. Preparation

NIST prepared digital latent and tenprint files for each study participant and provided them to the CLPEs. Files for each study participant were generated automatically via script to ensure uniform handling during preparation.

3.1 Latents

For each latent fingerprint image provided, the data was first extracted by cropping the bounded region from a full-scene capture. Bounding coordinates were not rectangular and pixels not within the bound region were colored white. Next, the width and height of the image were calculated at 1 000 pixels per inch (ppi) (i.e., 393.7 pixels per centimeter, or ppcm)[2]. For example, an image that was $1\,000 \times 1\,000$ pixels at 1 200 ppi would be 833×833 pixels when downsampled to 1 000 ppi. If the image dimensions were less than 256×256 pixels, the image was centered in a larger image of white such that the image would be at least 256 pixels in each direction at 1 000 ppi. This *padded* image was then downsampled to 1 000 ppi and quantized to 8 bit grayscale. Padded, downsampled, and quantized images are—unfortunately—requirements of most of the latent friction ridge tooling (e.g., feature extractors, record encoders—see Section 4.1) available today and latent images are required to be 1 000 ppi by Electronic Biometric Transmission Specification (EBTS) Type 13 [8]. NIST also provided CLPEs with the full-resolution and full-color latent images for use in analysis.

Once the final latent image was prepared, all known information about the print, including the region of interest bounding coordinates that isolate the print from the white background, were encoded into an EBTS record. NIST also provided the image in Portable Network Graphics (PNG) format [9] for use in standard image processing tools.

3.1.1 Image Enhancement

NIST has each latent image available in an *original* form and an *enhanced* form. In the original form, the latent image appears just as it did when it was scanned or photographed without any image enhancements. In the enhanced form, the latent image has been modified with image enhancements by a CLPE in a way that helped visually boost the friction ridge structure for marking a region of interest in the full-scene capture. An example of the same image in both forms can be seen in Fig. 1. Both versions were provided to CLPEs, but the enhanced version was used during annotation. SD 302 includes both the original and enhanced versions of the latent images with CLPE annotation, since it is likely that the image enhancements that benefit a CLPE may not benefit an automated feature extraction algorithm. NIST generated the original version of this record by swapping the enhanced image with the original image within the EBTS record, to ensure both images had the same features recorded. Note that the CLPE performing annotations may have performed additional adjustments to the image during annotation, but those subsequent image enhancements were not preserved.

3.2 Exemplars

NIST provided the baseline exemplar set as well as tenprint rolled friction ridge images collected with the most accurate devices from the N2N data collection[3], as determined by false negative identification rates in *NIST Interagency Report 8210* [3]. All rolled exemplars were imaged directly at either 1 000 ppi or 500 ppi (i.e., 196.85 ppcm) in 8 bit grayscale. These properties work well as-is with modern friction ridge software tools. Images were encoded into EBTS records with all known metadata, including finger position, capture technology, and impression type. These records were provided along with PNG images to CLPE.

Segmented slap images were also provided to CLPE in both EBTS and PNG format[4]. Like the rolled impressions, the segmented plain impression images were imaged directly at either 1 000 ppi or 500 ppi in

[2] A latent fingerprint image would not have been captured at exactly 1 000 ppi for several reasons, such as if the fingerprint was imaged from a variable distance with a photographic camera, as is common for items processed chemically.

[3] Devices `U`, `V`, and `C` from SD 302.

[4] Devices `R` and `S` from SD 302.

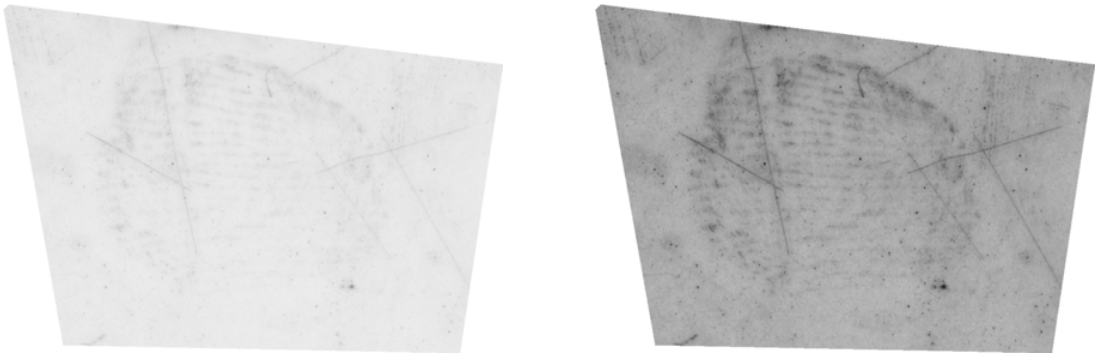

Fig. 1. A latent fingerprint image developed with black powder on the left, as-is after being scanned on a flatbed scanner, and with image enhancements applied to the same image on the right. The version on the right is easier for CLPEs to discern fingerprint features, but the enhancements on the right may not prove useful to automated feature extraction algorithms. Friction ridge imagery sourced from SD 302 [1].

8 bit grayscale.

While EBTS allows for storing multiple images of the same study participant in a single file, the workflow for this project was such that it was simpler for both NIST and CLPEs to interact with the exemplar records if they were stored with a single image in each record.

3.2.1 Tenprint Card

The CLPEs involved in creating this dataset routinely reference tenprint cards, such as the FBI FD-249, in actual casework. NIST created a tool that assembled the individual rolled and slap fingerprint images into a form that resembled the FD-249. These simulated cards were generated for all sets of exemplar rolls, each featuring the same slap images. A simulated tenprint card is shown in Fig. 2.

Fig. 2. A simulated tenprint card provided to CLPEs that mimics the tenprint cards routinely seen in casework. Friction ridge imagery sourced from SD 302 [1].

3.3 Spreadsheet

For each study participant, a single spreadsheet was generated. The spreadsheet contained a row for each latent image provided. Columns included a registry of information used to keep track of deliverables for the

CLPEs while providing a quick glance at results for NIST. Use of spreadsheet features such as fixed-choice cell values and conditional formatting helped ensure data was recorded correctly. Values were checked for consistency through a script run before deliverable acceptance (see Section 5 for more details).

Values appearing in the spreadsheet that do not appear in the delivered records include information about if the CLPE thought the comparison or print was interesting or unique in any way, or if the mark was believed to not be made by a distal phalanx, the latter migrating into dataset errata (Section 5.4). Relevant information will be communicated in future NIST publications.

The spreadsheet also included information regarding the results of running a commercial off-the-shelf (COTS) AFIS on SD 302. If the algorithm returned a finger position from the ground truth study participant anywhere in its candidate list from any of the exemplar sources, the information was reported to the CLPEs through the spreadsheet as a potential hint[5].

3.4 File Formats

EBTS records were distributed to CLPE in the form of Latent Friction Ridge Features Search (`LFFS`) transactions. EBTS specifies the expected contents of a record by the *type of transaction* field (`1.004`), which, in turn, tells a receiving AFIS how to process the record. In an `LFFS` transaction, latent friction ridge EFS features are extracted by a human and optionally sent along with an image. This aligns most closely with the actions performed by CLPEs in this project.

Another type of transaction used during this project was Image Request Response (`IRR`). These transactions represent enrolled image and feature records returned from an AFIS. In this project, an exemplar image would be considered an `IRR` after being completely annotated. NIST provided CLPE with a drag-and-drop tool to convert records between `LFFS` and `IRR` transactions to facilitate what is expected by available tools (Section 4.1).

[5]This technique had some consequences, as documented in Section 6.1.2.

4. Procedure

The steps followed by the CLPEs differ from typical casework because of various unique aspects of this project. However, like real casework, the ultimate steps performed approximately mimic the analysis, comparison, evaluation, and verification (ACE-V) methodology [10]. The procedure followed can be broken down into two distinct tasks: source determination and encoding, each with a verification step. All CLPEs performed all tasks at different times during the process.

4.1 Tools Used

CLPEs involved in annotating SD 302 primarily made use of Universal Latent Workstation (ULW)'s Latent Editor (LE) and Comparison Tool (CT), version 6.6.7 [11]. ULW is a software suite provided by FBI for CLPEs that allows for standards-based workflows of latent fingerprint data. The software was last updated in 2017. ULW's LE is capable of opening, editing, and writing `LFFS` transactions with EFS features, while ULW's CT is capable of comparing an `LFFS` to an `IRR`. Various other COTS software was considered, but in experimentation, none created the suite of fully compliant EBTS records required.

Due to severe image manipulation limitations in ULW LE, the CLPEs also made use of Adobe Photoshop [12] to enhance the clarity of images during examination. For example, while recording the EFS orientation (`9.301`) of a fingerprint is possible in ULW LE, rotating the image by that orientation such that the fingerprint is upright is not possible. This resulted in extra steps to transfer information between software programs.

4.2 Cursory Source Determination

The first step for this project was cursory source determination. Each study participant was assigned to a single CLPE so that the CLPE could quickly become familiar with the study participant's exemplar fingerprints. The CLPE opened one of the provided tenprint records on the right side of their screen and opened the latent image in question on the left side of their screen. After performing an initial quality assessment to determine the usability of the print, the CLPE examined the print and relied on their training to see if a source determination could be made to a fingerprint in the tenprint record[6]. If so, the CLPE recorded the finger position, took a screenshot, and annotated a few corresponding minutiae on both the latent and the tenprint card within the screenshot. An example can be seen in Fig. 3. This screenshot was used during a later verification and was **not** the final product.

For more difficult source determinations, the CLPEs examined other information provided by NIST:

- **Supplemental exemplars**: Exemplar fingerprints from outside the baseline exemplar set (i.e., captured with different hardware) would be reviewed to see if better quality ridge detail was available for comparison.
- **Scene images**: The full-scene capture could be consulted. The scene image showed other marks in the scene and could be used to determine hand anthropometrics, which may rule out several fingers.
- **Activity description**: Each activity in the data collection was prescriptive—the CLPE knew approximately the action that was performed, which could again be used to include or rule out certain fingers.
- **Latent to latent comparison**: In some cases, a latent image that had already been successfully sourced may have overlapping information with the latent being examined. Although this might not be acceptable in all casework, CLPE were permitted to use this technique for source determination within this dataset.

Using this additional information, the CLPE took a closer look at the tenprint card to attempt to make a source determination. It should be noted that latent to latent comparison and knowledge of approximate actions used when leaving a mark are not typical of casework, and are explored in Section 4.5.

[6]The intricacies of source determination are far beyond the scope of this publication.

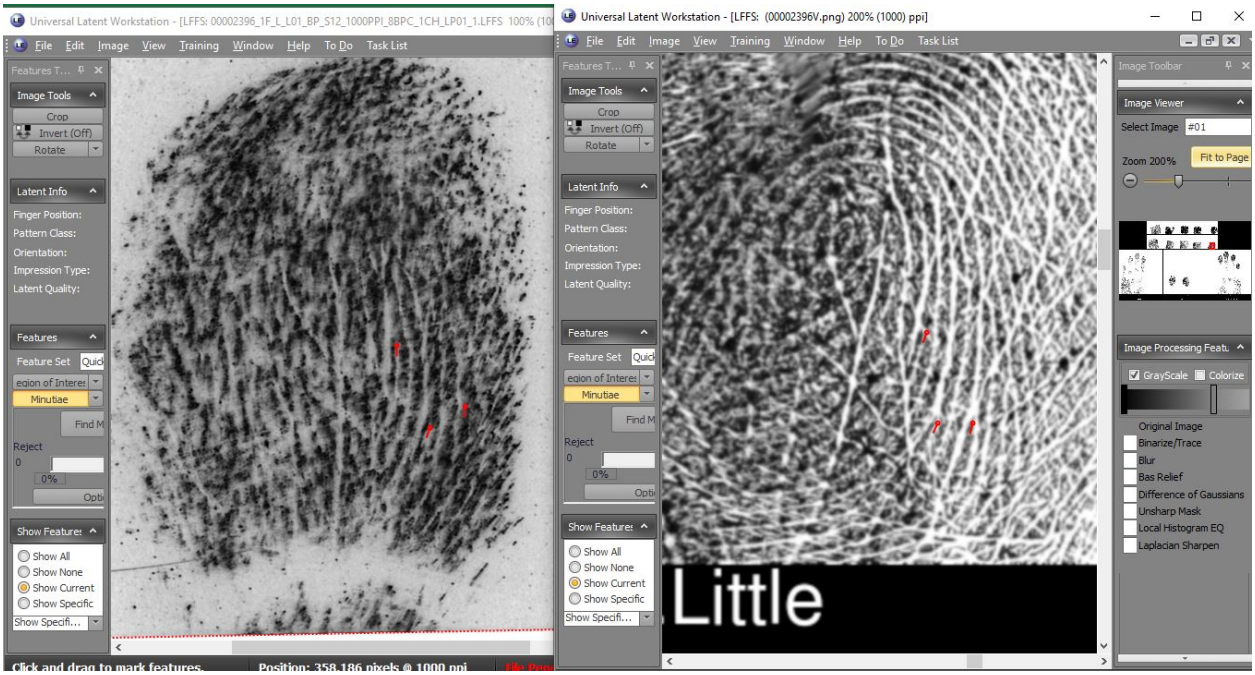

Fig. 3. An example of the cursory source determination process described in Section 4.2. The red dots annotated on the screenshot served as the basis for the source determination. Another CLPE would later encode these and other features with EFS in ULW LE. Friction ridge imagery sourced from SD 302 [1].

If a source determination still could not be made, the image was marked *no determination* and a reason for this decision was recorded.

4.2.1 Verification of Cursory Source Determination

A verification of the screenshot showing correlated minutiae was performed by a second CLPE. In the event that the image was skipped for any reason (e.g., initial quality, no overlapping region), the reasoning for source determination omission was verified. Because the images in SD 302 were randomly selected from the set of all distal phalanges recovered from the N2N data collection, it was not expected that every image be of the quality necessary for source determination.

4.3 Image Annotation

For each subject, CLPE annotated the ten rolled exemplars in the baseline exemplar set—one of each finger—with the features comprising EFS Profile 2. An example of annotating an exemplar rolled image can be seen in Fig. 4. If a CLPE was unable to use any of the ten exemplars from the baseline exemplar set for latent source determination, but was able to use a supplemental exemplar from SD 302 that was captured with a *different* device, this new exemplar image was also annotated with the features comprising EFS Profile 2. This means that for any given study participant, there may be more than ten fully-annotated exemplars. Annotation of EFS Profile 2 features of latent fingerprint images occurred simultaneously.

4.3.1 Verification of Image Annotation

A second CLPE verified the image annotations for each exemplar and latent fingerprint. The goal of this verification was to ensure that all visible minutiae were recorded in the image, that there were no false minutiae, and that all required EFS Profile 2 information was present and accurate. Annotation and verification of latent fingerprints occurred irrespective of the source exemplar.

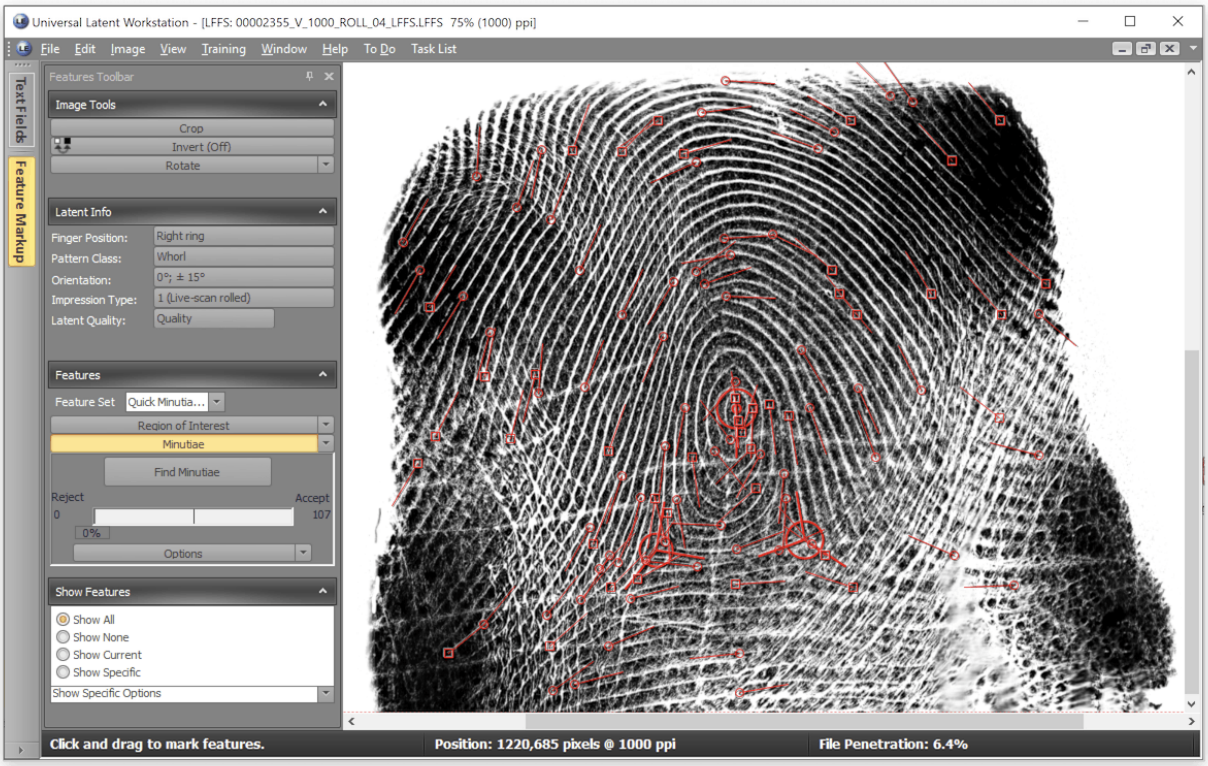

Fig. 4. Annotating an exemplar rolled image using ULW LE. Friction ridge imagery sourced from SD 302 [1].

4.4 Detailed Source Determination and Correspondence

Correspondence could begin after both the latent image and the exemplar used for source determination were annotated (Section 4.3). First, the CLPE changed the type of transaction of the exemplar to `IRR`, which was required for the exemplar to be processed appropriately in ULW CT. Then, the CLPE opened both records in ULW CT. The CLPE used their training to confirm with more rigorous detail that the source determination was accurate. They then marked several corresponding points between the latent image on the left and the exemplar image on the right. Finally, metadata about the correspondence was recorded, such as if the source determination was inconclusive. An example of correspondence being annotated can be seen in Fig. 5. Correspondence for exclusions were not recorded, as they were not necessary for SD 302.

When the CLPEs were able to ascertain the likely source of a latent mark, the correspondence annotations were fairly straight forward. Although not required, a number of *inconclusive* correspondence annotations were also included. In these cases, the CLPEs were not certain of the ground truth finger position for any number of reasons, but provided a possible set of likely corresponding minutiae for research purposes. Inconclusive source determinations were also recorded when a latent fingerprint could be sourced to one of the study participant's ten fingers, but with insufficient detail to be considered reliable (Section 4.5).

4.4.1 Verification of Detailed Source Determination and Correspondence

A third CLPE verified the cursory and detailed source determination decisions made by the previous two CLPEs. If the source determination was appropriately verified, the third CLPE would then verify minutiae correspondence and metadata.

If there were any differences in agreement, the third CLPE would rework the cursory source determination to come to a consensus decision. The screenshot of the cursory source determination would be placed back

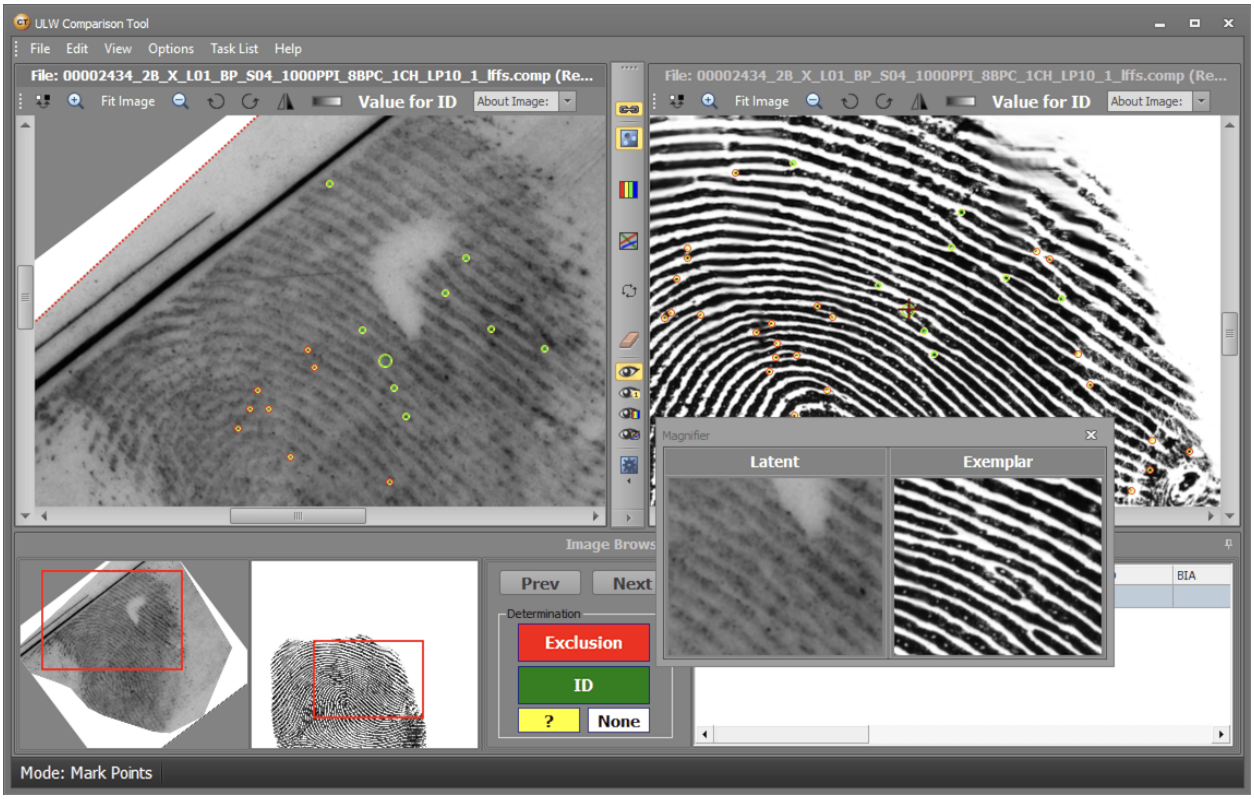

Fig. 5. An example of correspondence being annotated between a latent and a rolled exemplar image using ULW's CT. The *Magnifier* window zooms in on the corresponding minutiae in the latent and exemplar as indicated by the crosshair cursor in the exemplar image on the right. The green circles in each image correspond to each other and are encoded as a mapping in the underlying EBTS record. Friction ridge imagery sourced from SD 302 [1].

into the queue for re-verification.

4.4.2 File Formats

ULW CT writes a type of transaction (Section 3.4) for recording minutiae correspondence, referred to as Comparison (`COMP`). This transaction type is defined in Latent Interoperability Transmission Specification (LITS) [13]—not EBTS—to support the transmission of two friction ridge images and their associated annotations. This includes EFS fields that refer to correspondence such as *corresponding points or features* (`9.361`).

4.5 Shortcuts and Caveats

There were a number of factors known about the collection of the latent marks in SD 302 that would not be known in typical casework. This resulted in correspondence that might not be able to be supported operationally. For example, each latent fingerprint in the collection was associated with a specific activity, such as opening a window or sending text messages with a cell phone, giving clues as to the placement of the fingers. In casework, a detective may make assumptions about an activity, but it is not exactly known. Additionally, the data collection's inherent ground truth study participant affiliation protections limited the examination process to a single human source.

Because of this prior knowledge, some assumptions about hand placement could be drawn as a starting point. For example, one activity from the data collection was to pull a piece of tape from a larger roll of tape. As a starting point, a CLPE might reasonably assume that the end of the piece of tape would record the study participant's thumb on top and index finger on the sticky side. Fingerprints imaged from a cell phone's bottom home button might be expected from a thumb. As such, CLPEs were often able to do latent to latent comparisons. This allowed the CLPEs to group multiple similar latents and perform only a single comparison to the set of exemplar fingerprints.

In addition to being provided the distal latent for comparison, CLPEs were also provided the full-scene capture. Although these full-scene captures have purposely not been released to the public in order to preserve samples as sequestered data for testing in NIST's Evaluation of Latent Friction Ridge Technology (ELFT), they provide a broader context for which to base a source determination—-such as hand anthropometrics—and were provided under non-disclosure to CLPEs for the purpose of source determination.

A combination of these caveats can be seen in Fig. 6. The latent mark featured on the top left of Fig. 6 is part of SD 302. The corresponding baseline exemplars for the finger that left the mark available in SD 302 are pictured on the second row. The CLPE noticed that in the full-scene capture, there was another latent mark near the quality of an exemplar that showed the ridge detail, pictured in the upper right of Fig. 6. Using hand anthropometrics from this latent, the CLPE determined the ground truth finger position of the latent in question. Astute readers will notice that the ridge structure in the top-left latent found via the top-right latent is nowhere to be seen in *any* of the exemplars—counting ridges from the core to any of the annotated minutiae on the top-right latent results in regions not captured in the controlled scenario. Because no exemplar in SD 302 shows this region, the ground truth finger position was conservatively recorded as inconclusive due to no overlapping area.

Fig. 6. An example of when a latent to latent comparison may be useful. The latent in the top left of this figure is part of SD 302, along with the three exemplars in the second row. The mark in the upper right, while appearing to be of exemplar quality, is actually a latent impression from a full-scene capture featuring the study participant in question. The CLPE was able to source the upper-left latent to the upper-right latent (the red dots indicating corresponding minutiae, left to right in each latent), and then the upper-right latent to the exemplars, but could *not* determine the source of the upper-left latent *directly* to any of the exemplars due to lack of overlapping area. Friction ridge imagery sourced from SD 302 [1].

5. Clean Up

Although the EBTS records generated by ULW LE and CT are syntactically correct and usable as-is, they are not as complete as possible and may contain some semantic shortcomings, either due to operator error (e.g., missing an expected core on a loop-pattern exemplar) or a limitation of the software (e.g., not supporting encoding of a useful optional subfield). NIST post-processed the data distributed in SD 302 supplements to make the data as complete as possible.

5.1 Error Checking

NIST developed a script to help check files for completeness and consistency. This tool was used by CLPEs before sending files to NIST. In addition to assessing whether individual files and EBTS features were present, several basic tests were performed to ensure rational output. The script checked for semantics—content such as that rolled prints with a loop pattern class contained both core and delta points, or latents with an initial quality assessment of *value for identification* also had a source determination and comparison file. While not perfect, use of this script to catch and correct errors and omissions before distribution should decrease the amount of SD 302 errata published by NIST in the future.

5.2 EBTS Corrections

EBTS states that when minutiae (`9.331`), cores (`9.320`), and deltas (`9.321`) are not found, their respective EFS fields—which are optional—shall be omitted. However, if omitted, although the EFS Profile field (`9.303`) will be set to a value suggesting that a CLPE searched for them (e.g., EFS Profile 2), it's not obvious that these features were not found. EBTS provides corresponding *no feature present* fields (`9.334`, `9.325`, and `9.326` respectively) to help expose the lack of features more prominently. SD 302 employs these fields if features are not present. NIST inserted the *no feature present* fields when the records returned by the CLPEs did not contain the respective feature field. A complete set of EBTS fields can be found in Appendix A.

Other various cleanup tasks were performed with the records returned from ULW. For instance, ULW CT embeds uncompressed versions of both latent and exemplar images in the `COMP` transaction. NIST replaced these uncompressed images with the original, losslessly compressed versions, for file size considerations.

5.3 Extrapolation

As noted in Section 3.1.1, NIST has multiple color variations of the same friction ridge image content. While the CLPEs in this activity only annotated a single version of the latent, NIST was able to duplicate the records, swapping in alternate versions of the image. Additionally, NIST is able to extrapolate annotations to alternate resolutions of the image by scaling feature coordinates.

5.4 Errata

Having CLPEs look closely at each latent in SD 302 has been beneficial for identifying errata of all kinds in the dataset. For example, in Section 5.5 of [3], it was explained that all regions of interest were marked in the complete image of the scene and labeled as being a distal phalanx, intermediate or proximal phalanges, palm, or other/unknown. Without having the ground truth, these labels were educated guesses. Given the thorough examination in this activity, CLPEs identified some data entry issues, including images that were inappropriately labeled as being from a distal phalanx when they actually came from another phalanx or palm. As such, these have been noted in the SD 302 errata[7] and will be updated in a future revision to the dataset.

5.4.1 Overlapping Marks

Another example of a type of errata noticed during this project was overlapping marks. A few examples of this occurrence can be seen in Fig. 7. Each latent fingerprint file in SD 302 was supposed to represent a

[7] https://www.nist.gov/document/erratasd302txt

Fig. 7. A few examples of images from SD 302 containing multiple overlapping latent marks. Friction ridge imagery sourced from SD 302 [1].

single distal phalanx. However, the real world does not enforce that humans touch only unique locations on an item during their interactions. Several latent fingerprint images in SD 302 actually contained two or more overlapping impressions. In some cases, the previous CLPE determining the region of interest noticed the overlapping print and tried their best to crop to promote a single mark. In other cases, the overlapping mark simply went unnoticed when performing the single task of isolating regions of interest over several thousand images. Where possible during this task, the CLPEs duplicated these records and provided ground truth and correspondence information for each of the overlapping prints. These images are valuable to the research community and will not be altered in future revisions to SD 302, but they will be documented in SD 302's bundled documentation as containing multiple impressions.

6. Statistics

The data in this partial release of SD 302g–i encompasses data from 119 study participants originally released in SD 302. Several insights about the nature of the latent fingerprint images contained in the dataset can be gleaned from the following sets of statistics.

6.1 Overall

As of this publication in November 2021, there are 5 974 latent fingerprint images released as part of SD 302h, encompassing 119 study participants. This accounts for 50 latent fingerprints per study participant[8], including 35 unique images with two or more sets of annotation due to overlapping ridge detail (Section 5.4.1). Of these 5 974 latent fingerprint images, 2 814 or 47 % have a CLPE-verified source determination associated with them. Several hundred more have suspected source determinations to one of a study participant's 10 fingers, but the CLPEs cannot be certain. Over half of the dataset has no source determination.

6.1.1 Sufficiency of Baseline Exemplar Set

As explained in Section 4.3, a latent fingerprint may have correspondence linked to a supplemental exemplar (i.e., an exemplar not from the baseline exemplar set) if there was not enough overlapping region in the fingerprint from the baseline exemplar set. This occurred for 0.1 % of sourced latent fingerprints. That quantity is small, but the number of effected study participants is not. A supplemental exemplar was necessary for correspondence for over 73 % of study participants. This means to source at least 1 of 50 randomly chosen latent fingerprints in SD 302, the CLPEs needed to consult at least a second set of exemplars. Over 41 % of these study participants required at least three sets of exemplars. Multiple sets of exemplars are not always present in typical casework or searchable with an AFIS.

6.1.2 Comparison to Algorithm

Source determination performance obtained by CLPEs is far better than a small test using a COTS AFIS searching an enrollment set of 100 000 additional non-mated subject's worth of live scan rolled impression fingerprint images along with the same mated images provided to CLPEs (Section 3.2). That algorithm was able to source 790 latent fingerprint images (13 %) to 1 of the 10 fingers from the appropriate study participant. Of these, only 11 were not able to have a source determination confirmed by a CLPE. Upon investigation, the COTS AFIS always returns a fixed length candidate list, and the similarity scores returned for these 11 images were well below a calibrated threshold, indicating a non-mate. Additionally, 16 of the COTS AFIS's determinations did not align with the CLPE—meaning the algorithm and CLPE agreed on the study participant but not the study participant's finger. Again, for all of these latent impressions, the COTS AFIS returned a finger position from the correct study participant, but with a very low similarity score. There are two exceptions, both multiple impression latents (Section 5.4.1), for which both the COTS AFIS and CLPE identified different *correct* finger positions.

6.1.3 Examiner Analysis Assessment

The CLPE's first step in this process was to perform an analysis assessment of the initial value of each latent image, to help determine what the next steps in the source determination process would be. The assessment guidelines and codes used were that of *NIST Special Publication 500-290*, Table 61 [7]. A summary of the initial value assessment can be seen in Table 1.

6.1.4 Comparison Determination

One of the CLPE's final steps was to make a source determination for each latent fingerprint image. NIST had high certainty based on the collection techniques that each image was sourced from one of a study participant's 10 fingers. While this may have been true, CLPE could only make source determinations if

[8]Some errata (Section 5.4) resulted in mislabeled latent marks being removed, thus 5 974 images (5 937 unique images and 37 additional sets of annotations due to overlapping marks) instead of 5 950.

CLPE Analysis Assessment	Quantity	Percent
Value	2 454	41.1
Limited	942	15.8
No Value	2 576	43.1
Not a Print	2	0.0

Table 1. Summary of the CLPE's initial analysis of the value of each latent fingerprint image from SD 302h.

Examiner Comparison Determination	Quantity	Percent
Individualization	2 149	36.0
Inconclusive: Corresponding Features	636	10.6
Inconclusive: Insufficient Information	514	8.6
Inconclusive: No Overlapping Area	295	4.9
Exclusion of Source	7	0.1
Exclusion of Subject	3	0.1
No Determination	2 370	39.7

Table 2. Summary of the CLPE's final comparison decision for each latent fingerprint image from SD 302i.

there was sufficient evidence in the available exemplar fingerprints, and as such, a large number of source determinations were not possible. A summary of the determinations can be seen in Table 2. While there is much discussion of uniform language for testimony of friction ridge examinations in the literature and industry as of publication, NIST opted to use the comparison determinations standardized in *NIST Special Publication 500-290*, Table 68 [7].

6.2 Pattern Classification

One of the basic features annotated by CLPEs was classifying the pattern of the exemplar fingerprints. That information has been combined with the sex of the study participants in Fig. 8. Note that the overall female population of SD 302 is documented as 65 % in *NIST Interagency Report 8210* [3].

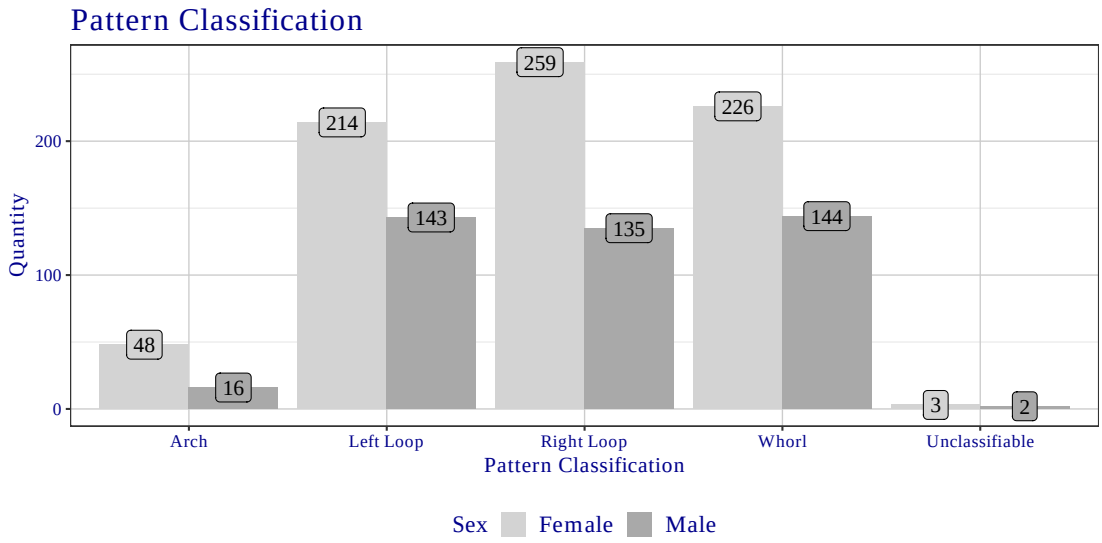

Fig. 8. Summary of the pattern classifications of exemplar fingerprints observed in SD 302g.

	Exemplar				Latent			
	Mean		*Median*		*Mean*		*Median*	
	CLPE	AFIS	CLPE	AFIS	CLPE	AFIS	CLPE	AFIS
Minutiae	113.0	92.3	107	92	10.2	10.8	5	9
Cores	1.1	1.2	1	1	0.3	0.0	0	0
Deltas	1.2	1.0	1	1	0.1	0.0	0	0

Table 3. A summary of minutiae counts for exemplar and latent fingerprint images from SD 302, as identified by CLPEs and a COTS AFIS.

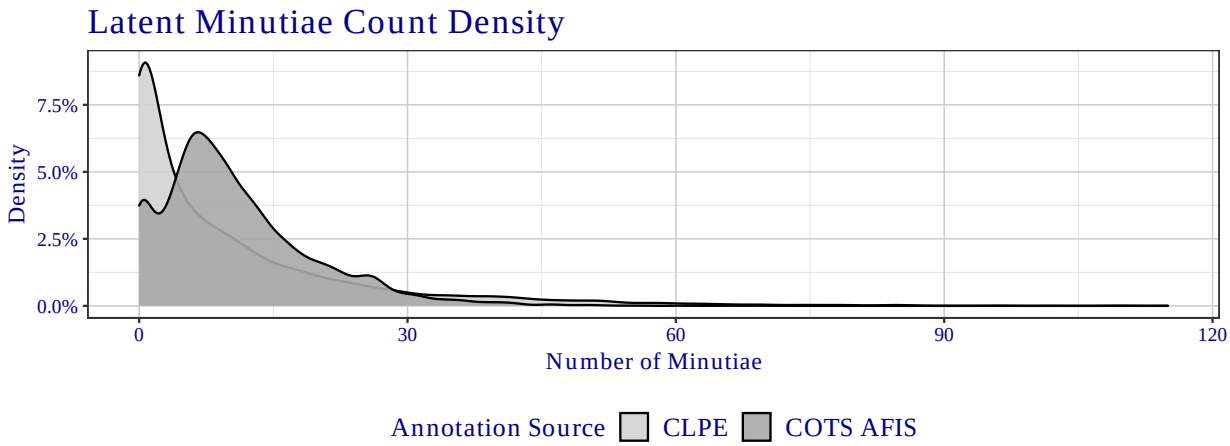

Fig. 9. Density of minutiae observed by CLPEs in latent fingerprint images in SD 302h, as compared to minutiae automatically encoded by a COTS AFIS.

6.3 Minutiae

On average, fingerprints in SD 302 analyzed by CLPEs contained less minutiae than when the COTS AFIS automatically encoded the same images. A summary of these values is in Table 3. No effort was made to determine the validity of the algorithm's automatically encoded minutiae positions.

A view of the density of minutiae that both CLPEs and the COTS AFIS observed in latent fingerprint images can be seen in Fig. 9. This shows that the vast majority of latent fingerprints contained 0 or a very small number of minutiae according to the CLPEs. This corresponds to the large number of *No Value* impressions, confirmed by breaking down the minutiae counts by the analysis assessment provided by the CLPEs, as seen in Fig. 10. The median number of minutiae in *No Value* latents is 0, with a mean of 0.84, as determined by CLPEs. Note that NIST randomly selected latent images for SD 302 rather than hand-picking images of a perceived quality.

One final overview summary worth noting with regard to minutiae counts is the effect of the number of minutiae on the ability of a CLPE to determine the source from a fixed set of ten fingerprints. This can be seen in Fig. 11. On average, the number of minutiae needed to determine the source is outside the interquartile range of the number of minutiae present when no source identification could be made. When subsetting by the CLPE's analysis assessment, as seen in Fig. 12, the ranges sometimes overlap. This helps to show the advantage that the human CLPE has when considering all the information presented to them (e.g., other latent impressions, knowledge of the activity, labeled subject evidence) toward assisting in a source determination that advances forensic science metrology, *not* criminal prosecution. Equivalent distributions are shown when separating by the image-only COTS AFIS's source determinations in Fig. 13 and Fig. 14, maintaining the observation. Interquartile ranges of COTS AFIS minutiae counts overlap significantly for *Value* prints, indicating no particular correlation between number of minutiae and search accuracy.

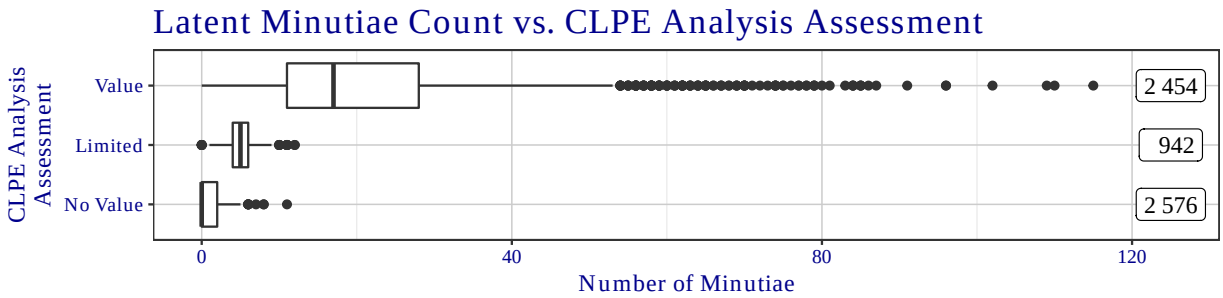

Fig. 10. Number of minutiae observed by CLPEs in latent fingerprint images in SD 302h, separated by the analysis assessment observed by the CLPEs. The number to the right of each box plot is the number of latent fingerprint images in each set.

6.4 Lessons Learned through Statistics

Exploring the minimal amount of information presented in Section 6 raises some lessons that can be learned before distributing new datasets of latent fingerprint images. Having the latent fingerprint images comprising SD 302 be chosen by random selection certainly creates challenges for some prospective users of the datasets, but it simultaneously creates great opportunities for others. For instance, having a large percentage of images that cannot be mated might not necessarily help advance all types of measurement in the forensic sciences, such as those requiring minutiae correspondence data. However, this distribution of *Value* and *No Value* impressions *is* typical of operational casework.

In many cases, images could not be reliably mated due to the impressions being from extreme tips and sides of the distal phalanx. Again, this is typical of operational casework. A proper rolled fingerprint should capture, "from nail to nail" [14], referring to the left and right edges of the fingernail bed, as the name of the N2N Fingerprint Challenge insinuates. The funded goal of the data collection was to support development of new rolled impression equivalent capture devices. Had more complete exemplars been captured, latent impressions sourced from extreme edges should have had a higher likelihood of being mated, thus indicating either a failure of the technology or the operator. Even still, not all rolled fingerprint impressions contain extreme tips. NIST did not collect complete friction ridge exemplars (e.g., *major case prints*), which would have included rolled tips and an overall more extensive exemplar capture. Future data collections should overcome this defect by collecting more exemplar areas to ensure maximum usability of the resulting latent marks. Additionally, SD 302 currently only includes the distal phalanx. NIST has latent impressions of palms and joints from the initial data collection that have yet to be analyzed, annotated, or released. At this point, similar defects in exemplar collection would be expected for latent marks from other regions, especially medial and proximal joints.

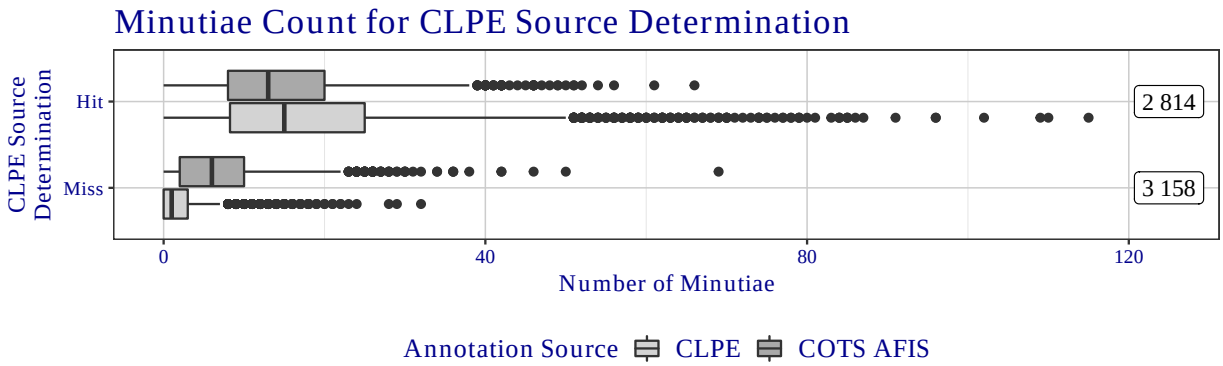

Fig. 11. Number of minutiae observed by CLPEs and a COTS AFIS in latent fingerprint images in SD 302h when a CLPE was able to determine the source of the print or not. The number to the right of each box plot is the number of latent fingerprint images in each set. A *hit* is considered a successful source determination to a finger from the expected study participant. Images with an analysis assessment of *Not a Print* (Table 1) were removed. This figure is comparable to Fig. 13, where minutiae counts are separated by COTS AFIS source determinations.

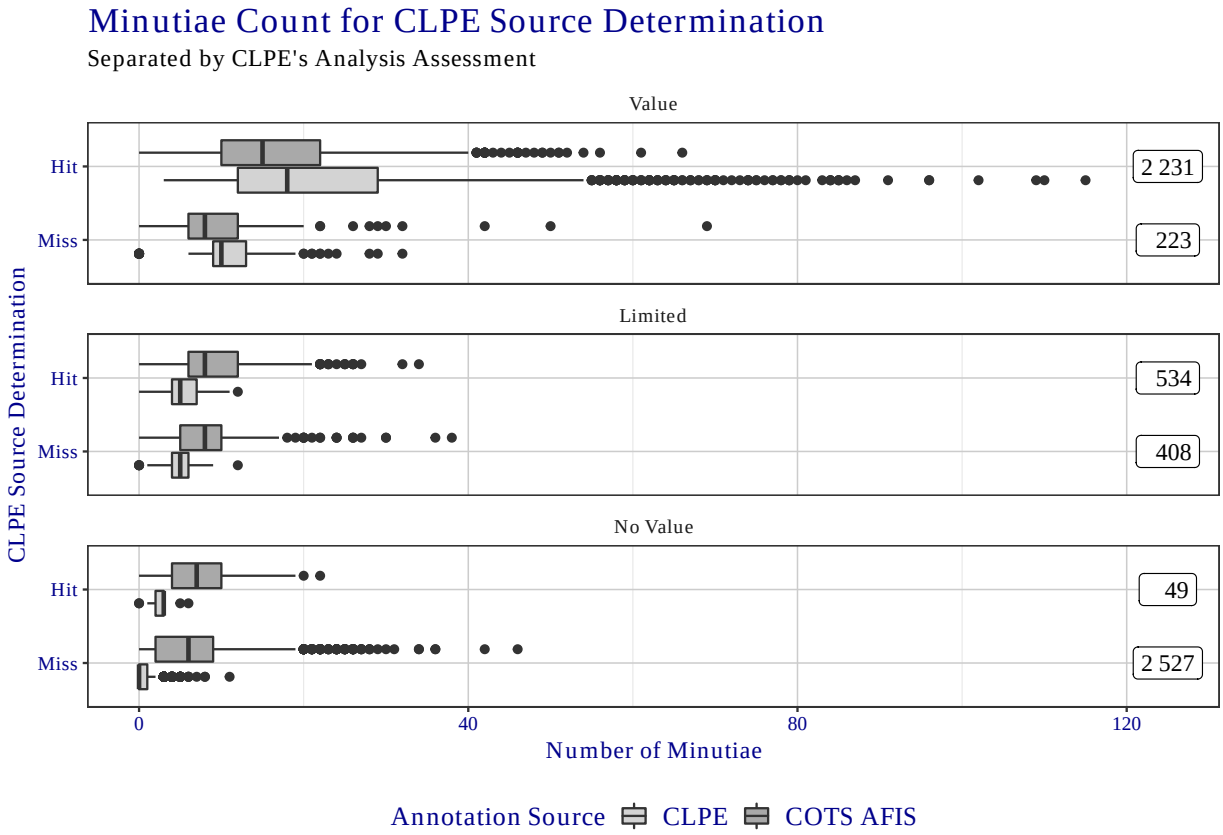

Fig. 12. Number of minutiae observed by CLPEs and a COTS AFIS in latent fingerprint images in SD 302h when a CLPE was able to determine the source of the print or not, separated by the CLPE's analysis assessment. The number to the right of each box plot is the number of latent fingerprint images in each set. A *hit* is considered a successful source determination to a finger from the expected study participant. Images with an analysis assessment of *Not a Print* (Table 1) were removed. This figure is comparable to Fig. 14, where minutiae counts are separated by COTS AFIS source determinations.

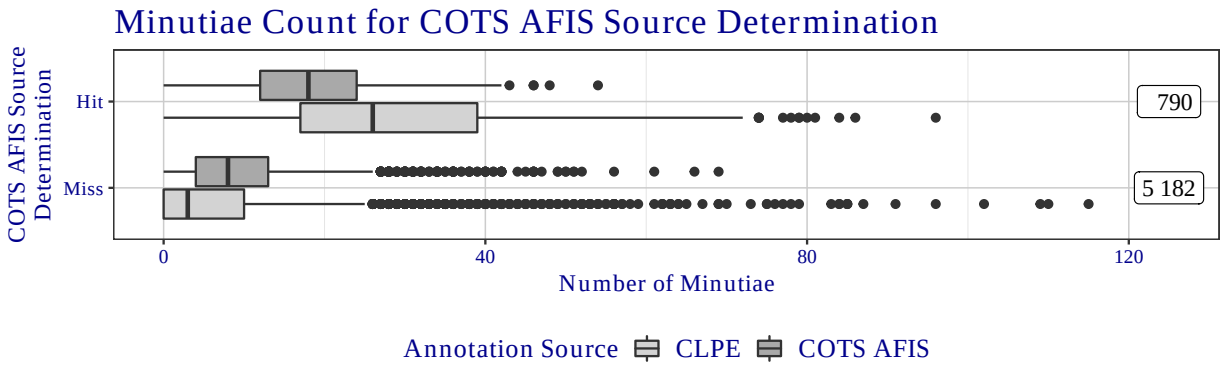

Fig. 13. Number of minutiae observed by CLPEs and a COTS AFIS in latent fingerprint images in SD 302h when a COTS AFIS was able to determine the source of the print or not. The number to the right of each box plot is the number of latent fingerprint images in each set. A *hit* is considered a successful source determination to a finger from the expected study participant. Images with an analysis assessment of *Not a Print* (Table 1) were removed. This figure is comparable to Fig. 11, where minutiae counts are separated by CLPE source determinations.

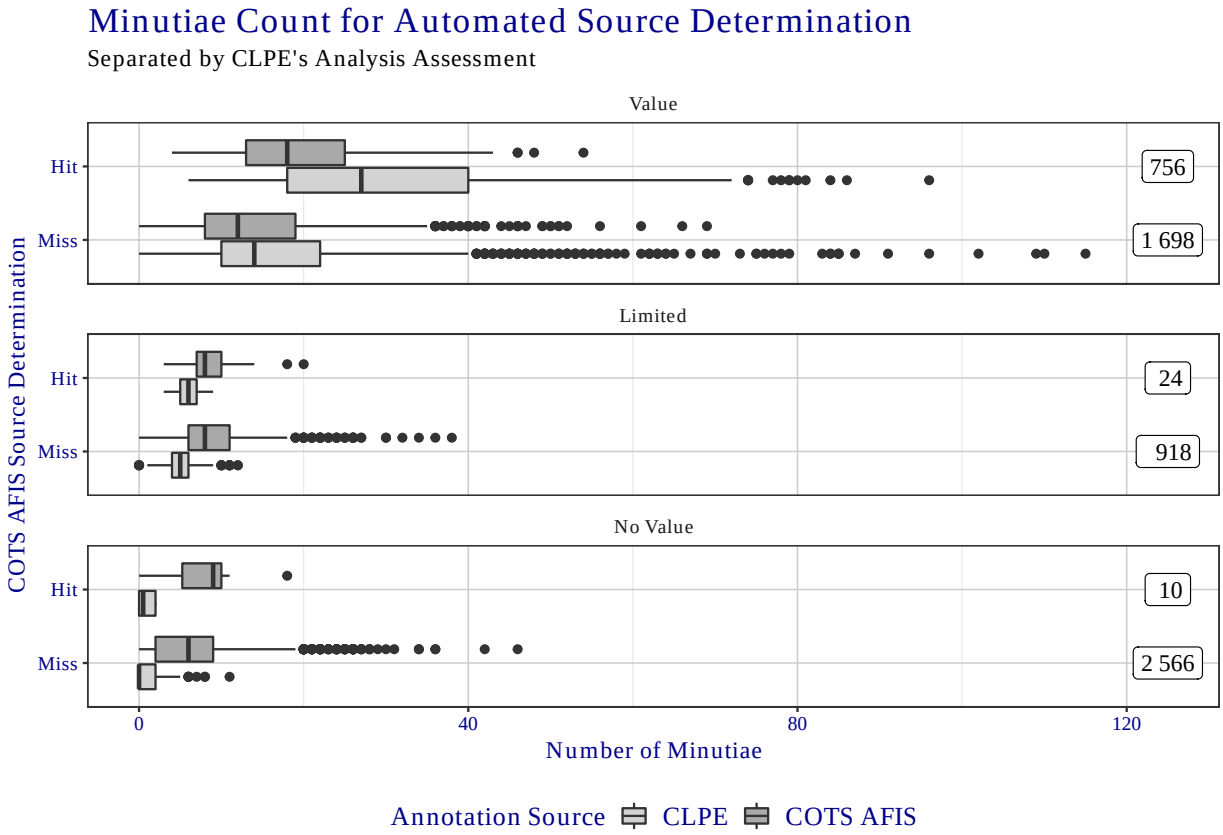

Fig. 14. Number of minutiae observed by CLPEs and a COTS AFIS in latent fingerprint images in SD 302h when a COTS AFIS was able to determine the source of the print or not, separated by the CLPE's analysis assessment. The number to the right of each box plot is the number of latent fingerprint images in each set. A *hit* is considered a successful source determination to a finger from the expected study participant. Images with an analysis assessment of *Not a Print* (Table 1) were removed. This is comparable to Fig. 12, where minutiae counts are separated by CLPE source determinations.

7. Obtaining and Using SD 302 Annotations

The datasets can be downloaded from the Internet for free by visiting our website, https://www.nist.gov/itl/iad/image-group/special-database-302. Before downloading, researchers must agree to the terms and conditions that are listed on the web page. Upon approval, a unique, time-sensitive URL is e-mailed to the requester for download.

Note that SD 302 is a series of distributions, each containing a logical subset of the N2N Fingerprint Challenge data collection images. For instance, SD 302e contains only latent friction ridge imagery in PNG encoding as generated by the Challengers. A description of subsets is available on the SD 302 website. The annotations mentioned in this document are part of the distributions named SD 302g (annotated exemplars), SD 302h (annotated latent distal phalanx, original), and SD 302i (correspondence).

The directory structure of SD 302 after expanding the downloaded archive can be found in Fig. 15. This directory structure was chosen to allow for NIST to easily deliver future versions of the same images in different file formats alongside the series of partial distributions that make up the entirety of SD 302. New to SD 302g–i are the `baseline/irr`, `challengers/irr`, `latent/lffs`, and `latent/comp` directories.

Information about file naming and the other SD 302 distributions is thoroughly documented in *NIST Technical Note 2007* [1] and not duplicated here. Note that because of latent images with multiple impressions (Section 5.4), the `NUMBER` field in the filename has been suffixed with a hyphen and second number (e.g., `LP11-2`, `LP03-1`) in order to distinguish unique impressions.

7.1 Validity

A comma-separated value (CSV) file, `checksum_latent_`**`EXT`**`[_`**`COLOR`**`].csv`, accompanies every directory of files. Contained in this file are the Secure Hash Algorithm (SHA) 256 checksums of the files contained within the named directory. Additionally, all image types contained within EBTS records have the optional *hash* field (`13.996` and `14.996`) containing the SHA 256 checksum of the embedded image data.

7.2 Tools

A variety of software tools existing for parsing EBTS and other record types conformant to *NIST Special Publication 500-290*. NIST distributes the source code to `an2ktool` and `an2k2txt` as part of its NIST Biometric Image Software (NBIS) package [15]. NIST also distributes Biometric Evaluation framework, a software library which, in part, allows parsing of records in C++ [16].

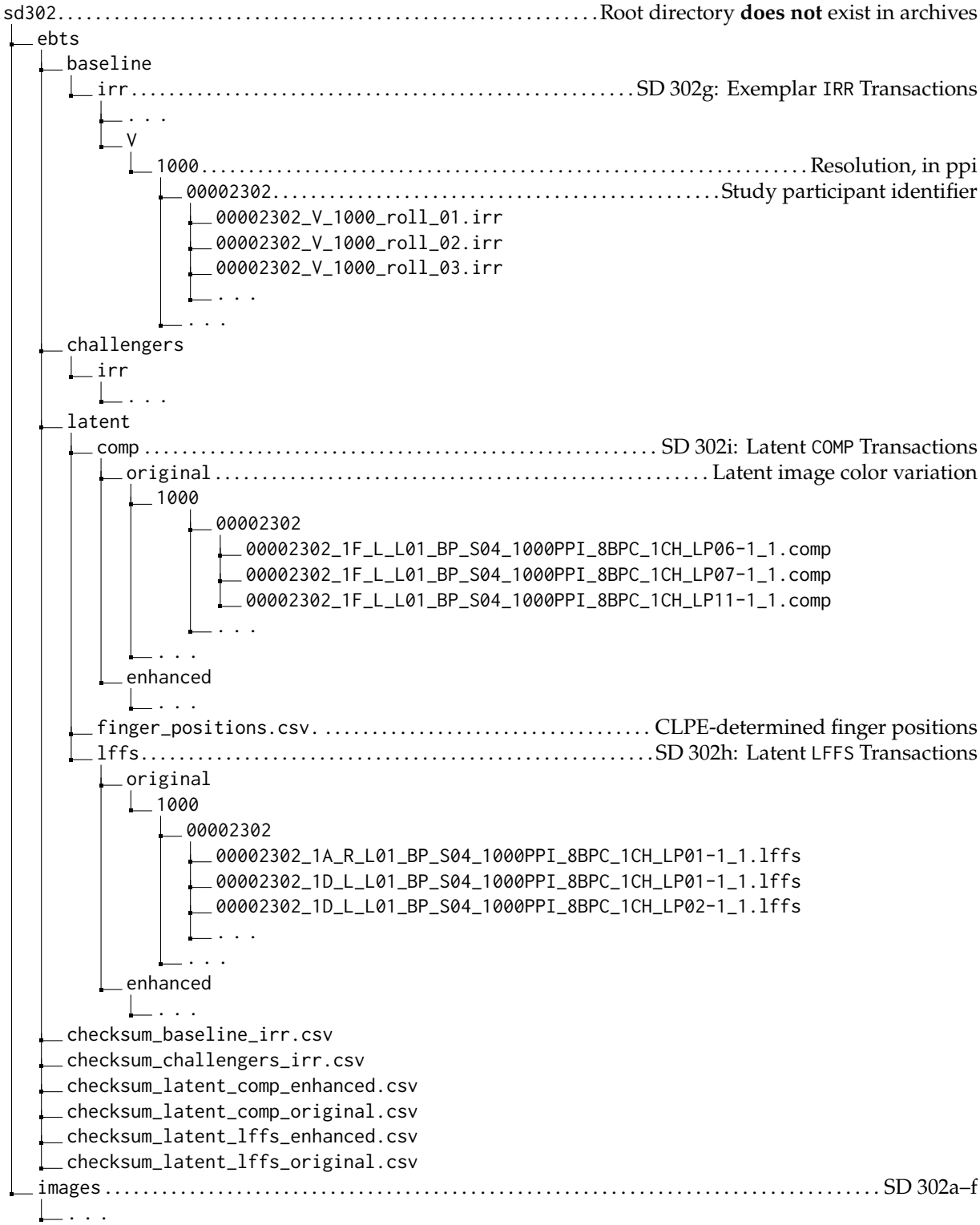

Fig. 15. Example directory listing of files in SD 302, specifically highlighting files new to SD 302g–i. For an explanation of filenames, refer to *NIST Technical Note 2007* [1].

A. Summary of Extended Feature Set Fields

Tables 4 and 5 contain brief descriptions of the possible EFS, LITS, and EBTS Type 2 fields contained in the EBTS records distributed as part of SD 302. For a complete description of these fields and the EBTS format, please refer to *NIST Special Publication 500-290*, *FBI Document NGI-DOC-01078-11.0*, and *NIST Special Publication 1152* [7, 8, 13].

Field #	Description
9.300	Region of Interest
9.301	Orientation
9.302	Finger Position
9.303	EFS Profile Set
9.307	Pattern Classification
9.314	Tonal Reversal
9.315	Lateral Reversal
9.320	Cores
9.321	Deltas
9.325	No Cores Present
9.326	No Deltas Present
9.331	Minutiae
9.334	No Minutiae Present
9.350	Method of Feature Detection
9.351	Comment
9.352	Latent Processing Method
9.353	Examiner Analysis Assessment
9.355	Latent Substrate
9.361	Corresponding Points or Features
9.362	Examiner Comparison Determination
9.363	Relative Rotation of Corresponding Print

Table 4. EFS fields populated in SD 302's EBTS records.

Field #	Description	Details
2.0006	Attention Indicator	Always `NIST77403`
2.0010	Case Contributor Identification Number	Study participant identifier
2.0011	Extension of `2.0010`	Always `00`
2.0034	Pattern Classification	Used by ULW LE
2.0074	Friction Ridge Generalized Position	Used by ULW LE
2.1401	Case Description	Latent image name
2.1402	Case Name	Latent image name
2.1403	Image Number	Always `1`
2.1404	Impression Letter	Always `A`
2.1406	Source Transaction Reference	Exemplar and latent record filenames and positions

Table 5. LITS and EBTS Type 2 fields populated in SD 302's EBTS records. While many of these entries could be considered unnecessary for a dataset, they are included to maintain conformance with applicable transmission standards.

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