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ACEware Latent Fingerprint Identification
Research and Software Development

Final Technical Report

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Abstract

There is currently no widely-used standard method of detailed documentation of the latent print examination process: how or whether examiners annotate what they use as the basis for their conclusions varies widely among agencies, and when examiners do document their work, there is extensive interexaminer variation because there is no uniform training in feature-level documentation. There is a need for greater standardization of documentation through more rigorous and consistent training, and through tools for operational casework. ACEware seeks to address that problem by providing a platform for standards-based detailed annotation of the latent print examination process. ACEware is an innovative software tool for use in training new latent print examiners in standard, reproducible documentation of examination — as well as for use by experienced case-working latent print examiners in documenting actual casework. ACEware builds upon the Universal Latent Workstation (ULW), which allows users to create, edit, view, and manage latent fingerprint transactions. ACEware extends ULW by providing functionality that supports both instructor-led and self-led training, extending its functionality for non-AFIS casework, and providing the capability to create standardized data sets for research and training. Because ACEware documentation is based on an international standard — the ANSI/NIST Extended Feature Set — detailed documentation of a complex latent print examination can be exchanged with other examiners, or archived for future review. ACEware is being developed by Noblis in collaboration and consultation with several Federal, state, and local law enforcement partners.

Table of Contents

Table of Figures

Executive Summary

There is currently no widely-used standard method of detailed documentation of the latent print examination process: how or whether examiners annotate what they use as the basis for their conclusions varies widely among agencies, and when examiners do document their work, there is extensive interexaminer variation because there is no uniform training in feature-level documentation. There is a clear need to improve and standardize the documentation of casework: a need for examiners to be able to unambiguously and consistently document the features they use to justify their decisions. The purpose of ACEware is to fill that need by providing a software platform for standards-based detailed annotation of the latent print examination process — for use in training new latent print examiners in standard, reproducible documentation of examination, as well as for use by experienced case-working latent print examiners in documenting actual casework.

The ACEware project developed software that provides functionality to support the detailed documentation of latent print examination. ACEware also provides functionality to facilitate training and develop datasets for research or training, as well as functionality for documentation of operational casework.

The ACEware software application builds upon the pre-existing Universal Latent Workstation (ULW) application provided by the Federal Bureau of Investigation (FBI) Criminal Justice Information Services (CJIS) and developed by Noblis.[1] ULW provides latent print examiners with tools to mark-up latent print images; submit latent print searches to local, state, and federal Automated Fingerprint Identification Systems (AFIS) including the Next Generation Identification (NGI) system; perform comparisons of latent prints and returned candidate images; and provides latent print case management tools that store and sort transactions related to operational casework. By building on ULW, ACEware is able to take advantage of the extensive capabilities of the ULW platform, and the ACEware functionality can be freely distributed to law enforcement agencies as part of ULW.

ACEware introduces new capabilities to ULW for use in a variety of situations including casework, training, and research. These capabilities include:

1. Data set based, instructor led training and data set or file based, self-led training:
   o Instructor led training typically consists of Lessons composed of individual Sessions. Lessons contain the files to be used for training, based on selected data sets, and cover the overall theme or concept to be taught. Each Lesson contains one or more Sessions in which student and instructor users are identified by Groups created and managed by administrative users. Each session within a lesson can contain the same student and instructor users, similar to a class that meets multiple times a week, or completely different groups can be identified for each role across different sessions within a single lesson. Sessions may also contain appropriate answer files that are linked to the individual files within a lesson to be used as a basis for automatic grading of student work upon completion. Users in a session's "student" role have access to an examiner training

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[1] *ULW was designed by Tom Hopper (FBI CJIS) and Austin Hicklin (Noblis, then named Mitretek) starting in 1998, and has been developed and maintained by Noblis ever since then, under contract to the FBI.*

dashboard that displays the work to be completed, the student's individual progress on a lesson, and any metrics that may exist as a result of grading against an available answer file. Students are able to open each file within a lesson to perform markup within the appropriate ULW application, and subsequently check-in their work upon completion. Students also have the option of viewing their own markup and the markup contained within an answer file as an overlay on a single image to better understand how their work compares to the answer after grading has been performed. Users in a session's "instructor" role have access to their own instructor dashboard allowing them to see the progress the class as a whole, the progress of each individual student within a class, as well as any metrics that are generated as a result of "grading" a student's work against the appropriate answer file, if available. Instructor users also have the ability to view multiple student's markup on a single image for the purposes of discussion and developing an understanding of consensus levels among students.

o Self-led training can be accomplished in a manner similar to instructor led training where a user may play the role of both student and instructor for a data set based lesson. Users also have the option of selecting one or more markup files to load as an overlay on top of their own markup within the Latent Editor application, allowing an individual to compare themselves against ground truth data or other examiners in the field at any time. This provides examiners with the same comparison functionality available to instructor users and provides a means for individual examiners to test themselves outside of structured training scenarios.

2. Creation and management of datasets for use in research or training, including the ability to set relationships between all files contained within the dataset. The intent is to propose a standard specification for friction ridge datasets that can be used in the dissemination of future datasets.

3. Comparison or consolidation of the markup of a single latent print by multiple examiners. Comparison of markup can be used to facilitate discussion in training scenarios, to analyze key differences between examiner mark-up (interexaminer variation) and identify potential red flags or areas of improvement, and to compare against ground truth data. Combination of markup can be used to develop "ideal" markup for training datasets, or to develop consensus among multiple examiners.

4. A variety of enhancements to ULW to enable non-AFIS casework, including:

o The ability to perform blind or non-blind verifications from within the ULW software application. In a blind verification, the original examiner's markup and conclusion are removed and the verifying examiner is given only the latent print and a single candidate exemplar; in a non-blind verification, the verifying examiner is given a copy of the original examiners' work, including all marked features and conclusion, in order to review the work performed. In the event both examiners come to the same conclusion, the comparison has been successfully verified and is marked as such within the software. If the examiners come to conflicting conclusions, a conflict will be registered in the software as flag for administrative users to begin a conflict resolution process.

- o Individual feature annotations. Feature-level comments allow examiners to record any pertinent information about a particular feature marked during the analysis, comparison, or verification stages of the examination process. This provides a method by which examiners may communicate why or how a particular feature was marked and can be used by verifying examiners in a non-blind verification process, review boards, and may even serve as a basis for discussion within a court room presentation.
- o Basic QA reporting capabilities. Quality Assurance reports may be generated to flag files for "review" and "rigorous review" based on analysis markup and retained markup between analysis and comparison stages of the examination process. Markup Summary reports display a distribution of features with respect to the examiners' assessments of value and comparison conclusions. Both of these reports were designed to help ensure sufficient levels of detailed analysis are being performed and to pinpoint areas in need of improvement. This reporting functionality also serves to demonstrate the types of automated QA made possible by ACEware.
- o Expansion of Extended Feature Set (EFS) data field support, specifically within the ULW Comparison Tool. EFS fields such as Method of Feature Detection, Latent Processing Method, Evidence of Fraud, Latent Substrate, and Latent Matrix were previously only available during the analysis stages within ULW Latent Editor. With ACEware, examiners are able to enter and modify EFS field data and save such entries to COMP files for exchange between examiners, organizations, and for record keeping.

The project involved collaboration with the law enforcement agencies that were our official partners (Fairfax County Police Department, New York State Division of Criminal Justice Services, and Arizona Department of Public Safety Crime Laboratory), as well as additional testers (FBI Laboratory, Royal Canadian Mounted Police, and Cuyahoga County Regional Forensic Science Laboratory). An Alpha test version was released for feedback in January 2015. Beta test versions were released in March 2015, November 2016, and early December 2016.

The reactions to the ACEware functionality suggest the latent print community is indeed looking for and open to solutions for organizing casework in a consistent manner, training examiners on proper markup methods, and electronic verification methods. Many have stated a desire and need for features such as data set creation and management (not just for training but for casework purposes as well), training, and verifications.

Beyond the specific functionality implemented in ACEware, adoption of ACEware is intended to improve the rigor, transparency, standardization, and quantifiability of the latent print examination process by:

- Providing a standardized approach for applying the ACE-V method, building upon SWGFAST standards and EFS
- Facilitating increased consistency and proficiency in feature selection and detailed documentation by latent print examiners
- Improving the resolution of disagreements between examiners and verifiers (conflict resolution)

- Standardizing formats for data exchange, long-term data archiving, and evidentiary presentations
- Providing a standard platform for collection of data and performance metrics
- Providing a basis for quantitative analyses of latent print examination, including automated metric-based quality assurance, and quantitative examiner performance evaluations

After the release of ACEware and completion of the development phase, future research can evaluate its effectiveness, and develop additional quantitative analyses of latent print examination.

1   Introduction

There is currently no widely-used standard method of detailed documentation of the latent print examination process: how or whether examiners annotate what they use as the basis for their conclusions varies widely among agencies, and when examiners do document their work, there is extensive interexaminer variation because there is no uniform training in feature-level documentation. There is a clear need to improve and standardize the documentation of casework: a need for examiners to be able to unambiguously and consistently document the features they use to justify their decisions. The purpose of ACEware is to fill that need. ACEware has been developed to address that problem by providing a software platform for standards-based detailed annotation of the latent print examination process — for use in training new latent print examiners in standard, reproducible documentation of examination, as well as for use by experienced case-working latent print examiners in documenting actual casework.

Over the past ten to fifteen years — in response to Daubert challenges,[2] the Mayfield misidentification, criticisms of latent print examination,[3] the National Research Council's report on forensic science,[4] and now the PCAST report on forensic science[5] — the latent print examination discipline has been undergoing a sea-change, reevaluating its basic tenets with the goal of improving the scientific basis for latent print examination.[6] ACEware was developed to be part of that process: to put software tools in the hands of examiners in order to improve the rigor of the latent print examination process.

1.1   ACE-V

Analysis, Comparison, Evaluation, and Verification (ACE-V) is the prevailing framework used to guide a latent print examiner through the analytical decision making process. In the Analysis phase, the examiner assesses the quality and quantity of features in a finger-or palmprint and determines whether the print is of value for further examination. In the Comparison phase, the features are compared with the features observed on a known (exemplar) print to determine corresponding features or discrepancies. In the Evaluation phase, the examiner determines whether there is sufficient information to make an individualization (identification) or an exclusion. The Verification phase of ACE-V refers to an independent reevaluation of the work performed during ACE.

1.2   The lack of standardized documentation

While ACE-V requires detailed evaluation of often complex data, this information is not generally documented in a rigorous, quantifiable, and repeatable manner. The Scientific Working Group on Friction Ridge Analysis, Study and Technology's (SWGFAST's) *Standard*

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[2] *Starting with US v. Mitchell in 1999 [Mitchell99], there have been dozens of challenges to the admissibility of fingerprint evidence.*

[3] *e.g. [Cole05,Cole06,Dror06a,Dror06b,Haber08,Haber09,Mnookin08]*

[4] *[NRC09]*

[5] *[PCAST16]*

[6] *Note that this report was written simultaneously with Mr. Hicklin's PhD thesis [Hicklin16]; some content, especially in the introduction, is shared without further attribution.*

for the Documentation of Analysis, Comparison, Evaluation, and Verification (ACE-V)[7] defines the types of information to be documented during routine and complex examinations, but does not attempt to make detailed requirements regarding how features are to be selected or to standardize formats for documentation.[8] Although SWGFAST directs examiners to document examination "such that another qualified examiner can determine what was done and interpret the data," frequently Analysis and Comparison [9] assessments are not documented in sufficient detail for another qualified latent print examiner to understand what information the examiner used in making determinations.[10] The details of how to document Analysis and Comparison are mostly unspecified, and SWGFAST's standards are unenforced, leaving the details to be sorted out by agency standard operating procedures or by the examiners' judgments. This practice can impair data integrity, increase susceptibility to bias, and compromise the sequential aspect of ACE-V, resulting in circular reasoning. The lack of standard procedures and underutilization of existing standard data formats (see Section 1.3) limits interchanges among examiners, long-term archiving of casework, validation, evaluation of examiner capabilities, quantitative analysis, and quality assurance.

The Department of Justice Inspector General's review of the Brandon Mayfield misidentification[11] and the National Research Council report on forensic science[12] were both critical of the lack of documentation of the latent print examination process. The Mayfield OIG report described how the lack of documentation contributes to circular reasoning,[13] and indicated that required documentation may result in more reliable conclusions. [14] The Mayfield OIG report recommends more rigorous documentation (Recommendation 10) and separate documentation of features observed in the latent during the Analysis phase (Recommendation 11). The NRC report also called for required documentation, for transparency and to "provide the courts with additional information on which to assess the reliability of the method for a specific case."[15]

Subsequent research has shown that examiners' value determinations and conclusions are not always reproduced by other examiners, and are not always even repeated by the same

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[7] *[SWGFAST-Doc12]*

[8] *The Scientific Working Groups (SWGs) have been replaced by the NIST-sponsored Organization of Scientific Area Committees (OSAC), but the existing SWG documents remain in force until OSAC replacement standards are formalized.*

[9] *Analysis and Comparison are capitalized when referring to the Analysis and Comparison phases of ACE-V.*

[10] *Based on discussions with a variety of examiners.*

[11] *[Mayfield06]*

[12] *[NRC09]*

[13] *[Mayfield06], p191-192*

[14] *"The absence of substantive documentation requirements is a conspicuous shortcoming of the current SOPs. We believe that there is a strong possibility that if the examiner and verifier had been required to document the analysis and comparison phases of their examinations, they might have noticed more dissimilarities and appreciated the cumulative impact of them before reaching their flawed conclusions. [...] We believe that documentation would have facilitated a more objective comparison and evaluation, regardless of the particular standard utilized to declare an identification." [Mayfield06], p202*

[15] *[NRC09] p 5-13*

examiners.[16] Such issues with reliability underscore the need to have clear and precise methods of documenting ACE-V. The recent FBI Laboratory/Noblis study *Interexaminer variation of minutia markup on latent fingerprints[17]* detailed the extent to which examiners differ in the minutiae they see and use as the basis for their decisions; this can be seen in large part as the result of the lack of standardized documentation in examiner training and operational casework.

The recent report on forensic science by PCAST underscored the importance of converting "latent print analysis from a subjective method to an objective method." [18] Although automation of much of the latent print comparison process may be desirable, that would be a very long-term goal; in the meantime, it is reasonable to take steps to improve the rigor of latent print examination, by making it more transparent, standardized, and quantifiable. One step in that direction would be to require standardized documentation, in training and in casework. The absence of detailed documentation indicating which features were used in making a given decision is problematic due to a lack of transparency: without detailed documentation the actions and inner workings of the decision process are neither visible nor accessible, and are not fully articulated for any consumer of an examiner's determinations (e.g. supervisors, other examiners, attorneys, judges). One effect of this has to do with the potential for bias: when comparing highly similar prints, the examiner runs the risk of confirmation bias or circular reasoning, in which additional features may be suggested during comparison based on the similarity. In the Mayfield misidentification, the initial examiner reinterpreted five of the original seven Analysis points to be more consistent with the (incorrect) exemplar.[19] Without separately documenting the features observed in the analysis and comparison phases, the examiner may not realize — and the consumers of the decision cannot know — whether such bias affected the decision.

In the past, detailed documentation of Analysis was often limited to that required for searches of Automated Fingerprint Identification Systems (AFIS), with proprietary instructions on which features to mark varying substantially by vendor. Other than for AFIS searches, most agencies do not require detailed markup to document the features of a latent in Analysis, nor corresponding features used in Comparison. Those agencies that do require markup vary substantially on how that markup is affected. Some agencies (even now) document minutiae using pinpricks in physical photographs. Some agencies annotate using general-purpose tools such as Adobe Photoshop: while this is reasonable at a small scale, such a generic format retains none of the semantics associated with the features; while another examiner, agency, or automated analysis tool could open and view the resulting file, the exact intentions of the original examiner would frequently be lost. More rigorous approaches have been implemented in the University of Lausanne's PiAnoS (Picture Annotation System) and Latentworks by Mideo Systems.[20] A limitation of both PiAnoS and Mideo Latentworks is that they are not (at least currently) standards-based systems and therefore detailed annotations in either cannot readily be exchanged with other systems,

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[16] *[Ulery11,Ulery12,Dror11,Langenburg09]*
[17] *[Ulery16]*
[18] *[PCAST16] p103*
[19] *[Mayfield06], p7*
[20] *[PiAnoS, MIDEO]*

have no interoperability with AFIS workstations, and cannot be relied upon for long-term archiving.

If detailed documentation were consistently used in casework, a variety of automated quality assurance tools could be used that would not otherwise be practical. For example, automated flagging of identifications based on suspiciously few features is only possible if such features are marked; automated flagging of examinations with extensive changes between Analysis and Comparison is only possible if the Analysis and Comparison features are always marked. Quality assurance procedures can take special steps (such as extra verification) for decisions that appear to be high risk — but only if the features used to justify the decision are documented in a machine-readable format.

1.3   ANSI/NIST-ITL and the Extended Feature Set

The Data Format for the Interchange of Fingerprint, Facial, & Other Biometric Information (ANSI/NIST-ITL) is the most recent revision of a series of standards that began in the 1980s. These ANSI/NIST standards have been extensively used as the primary method of communicating biometric information for law enforcement and other large-scale identification purposes. The ANSI/NIST ITL standards are the basis for biometric and forensic specifications used around the world, including the FBI EBTS, DOD EBTS, DHS IXM, Interpol's INT-I, and a wide variety of national, state, and local application profiles.[21]

Based on recommendations from SWGFAST, in 2005 NIST chartered the Committee to Define an Extended Fingerprint Feature Set (CDEFFS) to define a standard definition of friction ridge features. The committee included 47 representatives from various US Federal Agencies, SWGFAST, the US and international latent fingerprint community, and engineers from a variety of AFIS vendors. The result was the Extended Feature Set (EFS), which was formally incorporated into ANSI/NIST-ITL in November 2011.

The purpose of EFS is to define a quantifiable, standard method of characterizing the content of a fingerprint or other friction ridge image. EFS was designed to enable AFIS searches and responses, documentation of ACE-V casework (for archiving, interchanges among examiners, and courtroom presentations), review of examiners' work (for quality assurance, validation and technical review, and conflict resolution), automated quality assurance, and quantitative analysis for research.

Though EFS is now broadly used as a non-proprietary format for AFIS searches, it is not yet frequently used for markup of non-AFIS casework. To assist in the adoption of EFS by latent examiners, *Markup Instructions for Extended Friction Ridge Features*[22] was released as a NIST Special Publication, providing instructions to examiners in marking friction ridge impressions in accordance with EFS to maximize consistency among examiners. The *Extended Feature Set Training Tool*[23] implements the EFS Markup Instructions in free, web-based software. The *Latent Interoperability Transmission Specification*[24] defines standard transactions for archiving and exchange of casework, to provide a basis for long-term

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[21] *[NIST-AppProfiles]*
[22] *[Chapman13b]*
[23] *[EFSTT]*
[24] *[Chapman13a]*

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standardization of how latent print examinations are documented, exchanged, verified, reported in legal contexts, archived, and made available for quantitative quality assurance.

1.4   Moving toward probability models

A great deal of ongoing research is being conducted on statistical models designed to quantify the probability that a latent print came from a specified source. This work builds on decades of work on the measurement of fingerprint individuality,[25] statistics supporting fingerprint examination,[26] and AFIS algorithms.[27] The intent of these efforts would be for the examiners' decisions to be augmented or replaced with an estimate of the probability that two prints came from the same source.

An ironic implication of many of the current models is that they are attempting to replace the examiners' conclusions, but are increasing the reliance on the examiners' feature markup: the models generally do not extract features themselves, but use examiner markup as input. Since feature markup is not standardized, probabilistic models that do not automatically extract features are highly sensitive to the interexaminer variability of feature markup. For these reasons, probabilistic models are dependent on the standardization of feature markup. Probabilistic models may well be the wave of the future for latent print examination — but they are only going to be effective if the latent print discipline standardizes the training and operational use of feature markup.

1.5   Universal Latent Workstation (ULW) and ACEware

The FBI's Universal Latent Workstation (ULW) was developed starting in 1998 specifically as a tool for AFIS searching.[28] ULW provides latent print examiners with tools to markup latent print images; submit latent print searches to local, state, and federal Automated Fingerprint Identification Systems (AFIS) including the Next Generation Identification (NGI) system; perform comparisons of latent prints and returned candidate images; and provides latent print case management tools that store and sort transactions related to operational casework. ULW serves as a reference implementation of EFS. ULW has been used extensively for years to conduct AFIS searches, to great success.

ACEware extends ULW by providing training functionality, extending its functionality for non-AFIS casework, and providing the capability to create standardized data sets for research and training. By building on ULW, ACEware is able to take advantage of the extensive capabilities of the ULW platform, and the ACEware functionality can be freely distributed to law enforcement agencies as part of a standard ULW release.

Note the name "ACEware" is limited to the NIJ project: the software will be released as "ULW with ACE-V Enhancements."

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[25] *Survey in [Stoney01]*

[26] *Survey in [Neumann13a]*

[27] *[Wayman05, Maltoni09]*

[28] *ULW was designed by Tom Hopper (FBI CJIS) and Austin Hicklin (Noblis, then named Mitretek) starting in 1998, and has been developed and maintained by Noblis ever since then, under contract to the FBI.*

2   ACEware functionality

ACEware introduces new capabilities for use in a variety of situations including casework, training, and research. These capabilities include:
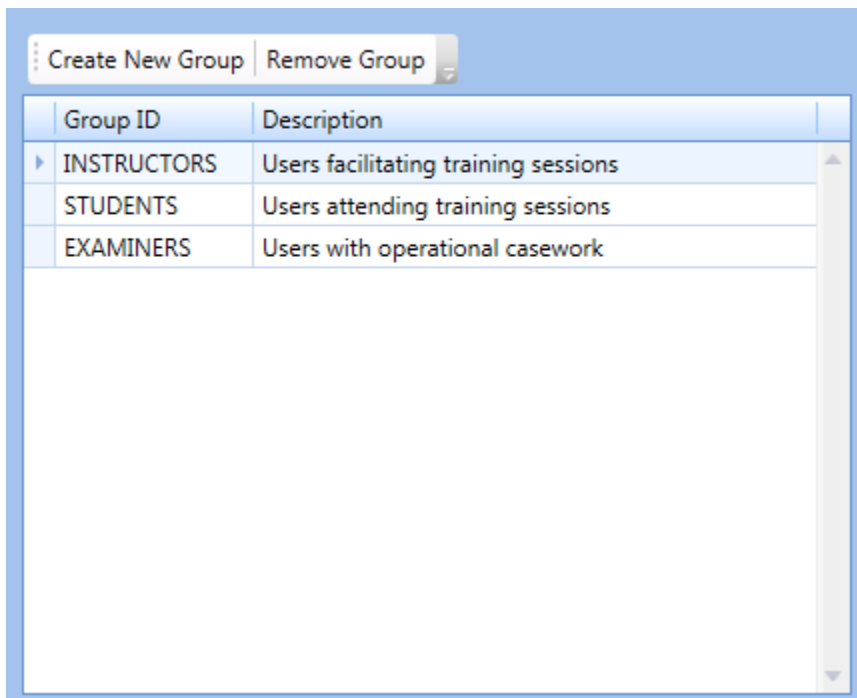
- The ability to facilitate instructor or self-led training
- Creation and management of data sets for use in research or training
- Comparing and combining minutiae markup by multiple examiners
- A variety of enhancements to ULW to enable non-AFIS casework

2.1   Training

In an effort to improve the level of detailed documentation performed by latent print examiners, as well as improve the quality of such documentation, ACEware was developed to facilitate classroom tutorials, self-training, and peer evaluation. By leveraging pre-existing tools within the ULW suite, training can be facilitated using the same tools that are available for operational casework allowing student examiners to immediately apply lessons learned. At the center of ACEware training is the ULW Transaction Manager, with ULW Latent Editor and ULW Comparison Tool serving as tools for completing coursework as well as tools for facilitating discussions within a classroom setting.

2.1.1   Instructor-led Training

Instructor-led training focuses on using data sets to create and run Lessons for use in classroom training with multiple student examiners. When Instructor-led training is required, administrative users create Groups of users within the Transaction Manager application (see Figure 1 below)
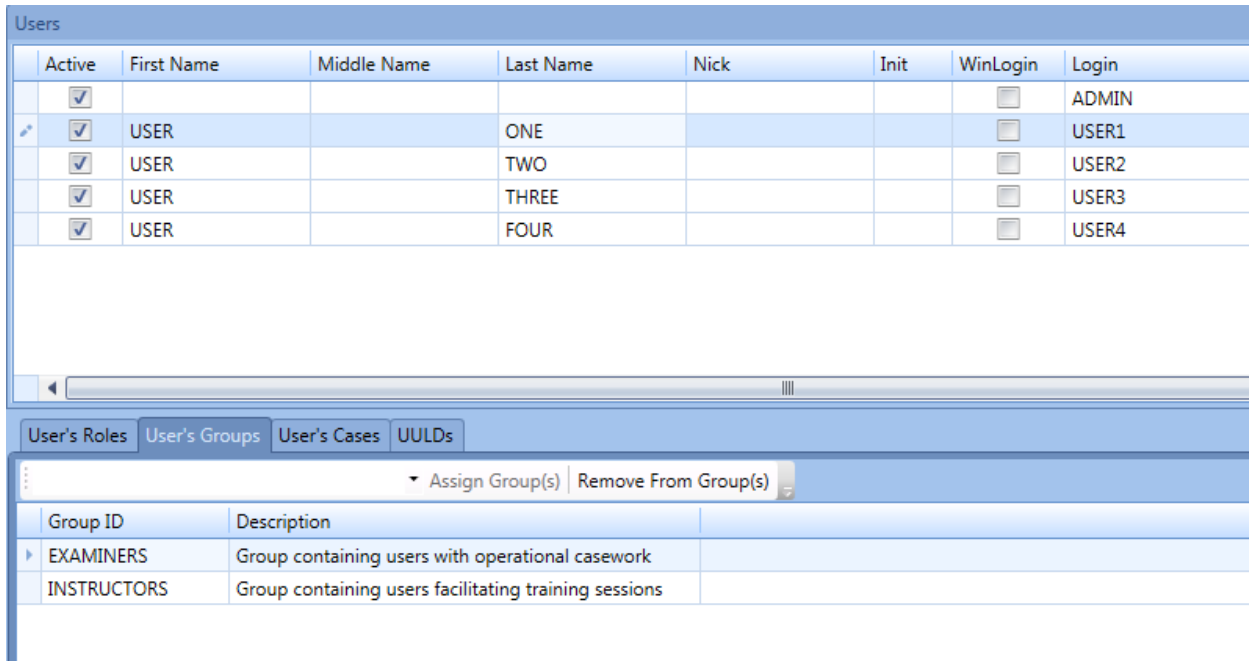
Group ID	Description
INSTRUCTORS	Users facilitating training sessions
STUDENTS	Users attending training sessions
EXAMINERS	Users with operational casework

Figure 1 – Example of Groups in Transaction Manager

These groups are mainly used to identify individuals assuming the role of Student and Instructor users for training but may also be used for grouping users as a means of identifying their roles within the application (e.g., Admins, Supervisors, Examiners, etc.); individual users may be assigned to multiple groups allowing administrators the freedom to create any number of groups for a variety of purposes, extending this Group concept to areas other than Training. Figure 2 shows an example of a single user with multiple group assignments.

Figure 2 - Multiple group assignments

After creating a minimum of two groups, one for instructors and one for students, users may begin creating Lessons.

When creating a Lesson, a user will identify a Lesson Name and provide any relevant details about that lesson in a Lesson Description.

Figure 3 - New Lesson form

Users will then select a data set or multiple data sets that have either been created using the data set creation and management functionality introduced by ACEware, or by importing a data set that is formatted in accordance with the dataset specification. The content of the data set will then become the content of the Lesson. Figure 3 shows a new Lesson form with basic information populated in each field and a data set selection. With basic information entered and a data set selected, the Lesson can be saved. A Lesson cannot be used for training until individual Sessions are created within that Lesson. Where a Lesson contains the content to be presented during training, a Session identifies the users and their roles for a single event in which the content of a Lesson will be presented.

Figure 4 - Populated Session form

Figure 4 demonstrates a Session "form" with the various options that need to be defined. Users will enter any pertinent comments they feel are important to note for the particular Session, select the Groups containing users that will assume the role of Students and Instructors for that session, the date scheduled, number of days to complete the Lesson content, and whether or not that Session is accessible by students. Session creation also provides users with the ability to link an answer file to the Lesson content as shown in Figure 5. Answer files are identified per Session rather than Lesson, allowing flexibility in what students will be graded against as training progresses.

Figure 5 - Answer files linked to Lesson content

Answers that are linked prior to the completion of Lesson content will cause student work to be graded immediately once that work is committed. Answers that are linked after a student has committed work will cause committed work to be graded as soon as the answer file is linked. In either case, so long as an answer file is available for a given Lesson file, work will be graded automatically. With a Lesson created and one or more Sessions created within a Lesson, students and instructors will now have access to their respective dashboards.
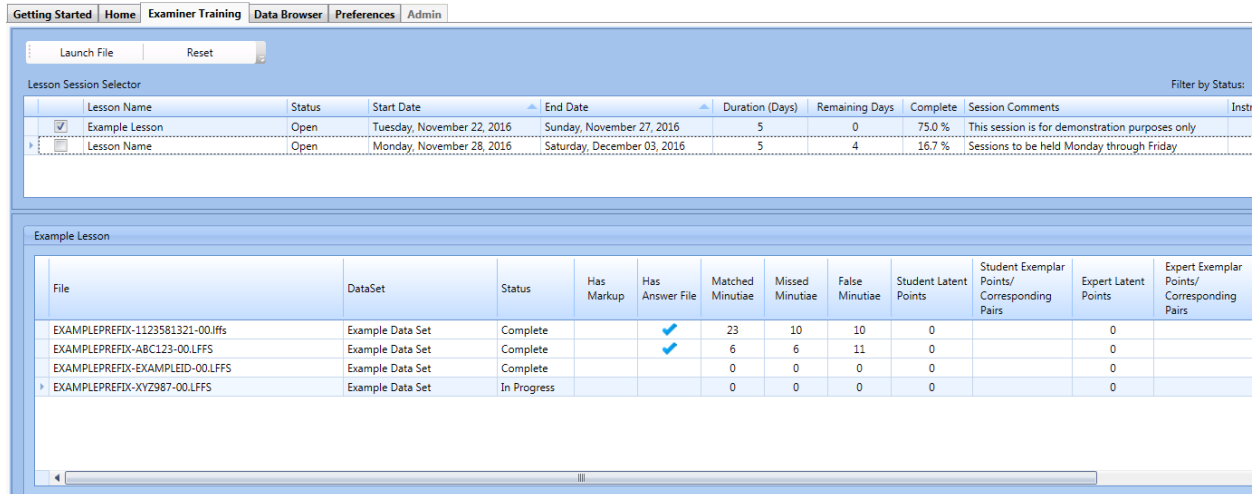
Figure 6 - Examiner Training dashboard

The student dashboard, or Examiner Training dashboard as seen in Figure 6, consists of two panels: the upper panel contains the Lessons in which the student is a part of while the lower panel consists of the content of a selected Lesson. By clicking the checkbox next to a Lesson name in the upper panel, the lower panel will display the content of the Lesson, the current status of the Lesson file, and any grading metrics that may be available. Double-clicking a row in the lower panel will open the selected file in the appropriate ULW application in order for a student to complete their work; image files and search files will automatically open in ULW Latent Editor whereas COMP files will open in ULW Comparison Tool. Once a student completes their work and closes the ULW application, they will be asked if they would like to save their work. After saving, or not saving, the student is asked if they have completed the assigned task for the file.
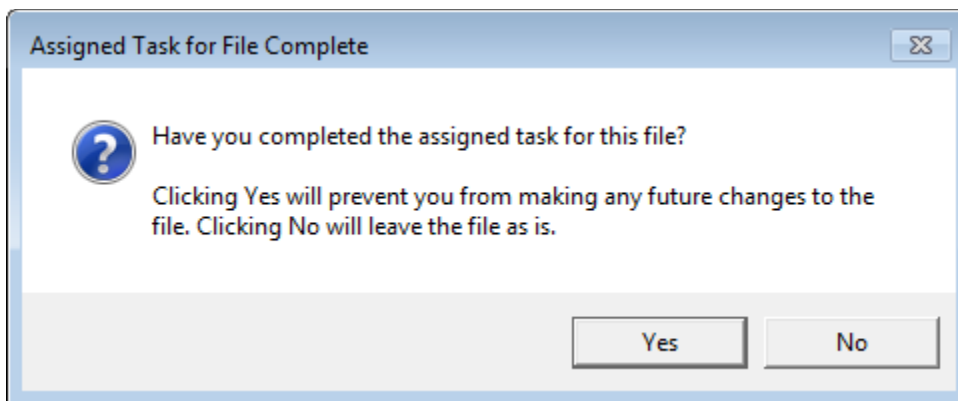
Figure 7 - Completion of assigned task prompt

If a student would prefer to continue working on the file later, they may choose to not commit their work – this will set the status of the file to "In Progress" and allow them to return to it later. On the other hand, committing work sets the file status to "Complete" and students will be unable to make further changes. Instructor users have the ability to override statuses in the event a student accidentally commits their work. Committed work will be graded if an answer file is available. If the student work was image or search file based, the student will receive a "score" in the form of Matched, Missed, and False Minutia

values. These values are based on the clustering algorithm described in Section 2.3 and can be described as:

- o **Matched minutiae** are features marked in both the student and answer files that are found to exist within the same cluster
- o **Missed minutiae** are features marked in the answer file but not within the student file resulting in clusters containing a features present only in the answer file
- o **False minutiae** are features marked in the student file but not within the answer file resulting in clusters containing features present only in the student file

Files that have been scored in this way can be opened again by the student examiner by double-clicking on the appropriate row. Opening a graded file will display both the examiners markup as well as the markup contained within the associated answer file as an overlay on a single image, as seen in Figure 8.
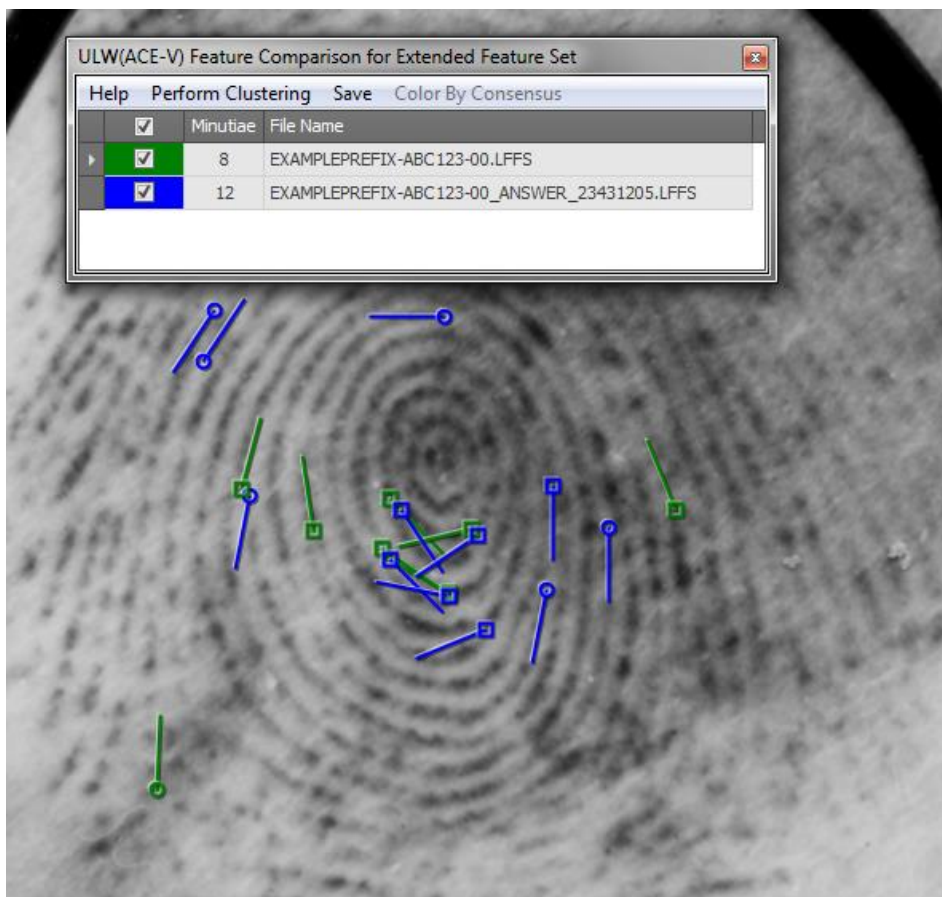

Figure 8 - Student and answer markup overlay

If a student performed work on a COMP file and an answer file is available, the student will see a listing of multiple data points (as opposed to Matched, Missed, and False values) including:

- o **Student Latent Points** – number of points marked on the latent print image by the student

- o **Student Corresponding Pairs** – number of corresponding pairs marked by the student
- o **Expert Latent Points -** number of points marked on the latent print image in the answer file
- o **Expert Corresponding Pairs** – number of corresponding pairs marked in the answer file
- o **Student Determination(s)** – the determination(s) marked by the student
- o **Expert Determination(s)** – the determination(s) marked in the answer file
- o **Student Latent Value** – the Assessment of Value marked by the student for the latent print image
- o **Expert Latent Value** – the Assessment of Value marked in the answer file for the latent print image
- o **Student Exemplar Values** – the Assessment of Value marked by the student for each exemplar image within the file
- o **Expert Exemplar Values** – the Assessment of Value marked in the answer file for each exemplar image within the file

Student examiners may continue to work on Lesson files until all work for a particular Lesson has been completed or are otherwise instructed to stop.

Figure 9 - Instructor dashboard

The Instructor dashboard, shown in Figure 9, is similar to the Examiner Training dashboard with some key differences. Instructors will see a list of the Lessons they are facilitating, including start and end dates, along with the progress of that Lesson; the Lesson progress represents the combined progress of all students assigned to a particular

Lesson. By selecting one or more Lessons via the checkbox to the left of a Lesson Name, an instructor may view the progress and available grading metrics for each student and each file contained with the selected Lesson(s). This data can be viewed in two ways:

- **View by Student** (as seen in Figure 10) displays data files according to the individual student to which that file belongs. This view helps provide a snapshot of a student's progress through a lesson along with any potential grading metrics that are available.

Figure 10 - View by Student mode

- **View by Data File** (as seen in Figure 11) displays the individual data files within a selected Lesson. Listed Lesson files can be expanded to display each student, including individual student progress and any available grading metrics for that particular file. This mode is especially useful for selecting multiple students' markup

for the purposes of comparing and combining markup, and for facilitating discussions in a classroom setting.

Figure 11 - View by Data File mode

Regardless of how Lesson data is viewed in the Instructor dashboard, instructors have the ability to select multiple files for comparison using the overlay functionality in ULW Latent Editor. Similar to a student viewing their markup and the "ideal" markup as an overlay in Latent Editor, an instructor may view any number of markup files on a single image. Depending on the active view, instructors may select each student under a Lesson file in the View by Data File mode or the same files under each student in the View by Student mode. Figure 12 shows an example of multiple students selected using the View by Data File mode.

Figure 12 - Multiple students selected in View by Data File mode

After making all of the desired selections, the **Compare Files** button located at the top of the Instructor dashboard can be used to open an instance of ULW Latent Editor that will display multiple sets of markup, one for each selection made in the Instructor dashboard, as an overlay on a single image, as shown in Figure 13.
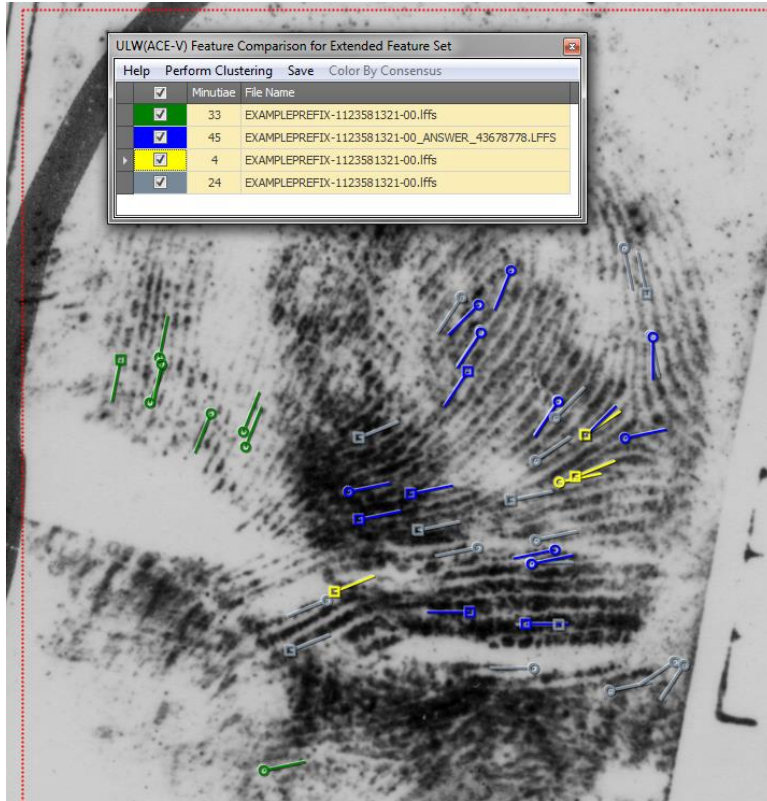
Figure 13 - Multiple student's markup, including answer file, on a single image

Viewing student markup in this way provides a basis for discussion within a classroom setting while maintaining anonymity among examiners and their peers. Instructors can toggle sets of markup on and off to compare and contrast the levels of detail marked by each examiner and to identify areas where improvement or additional focus may be required. If available, answer files will also be visible to compare groups of students against an "ideal" set of markup. Instructors also have the option of clustering student markup to display the consensus among examiners. Minutia clustering is described in detail in section 2.3.

2.1.2   Self-led training
Examiners may also wish to test themselves through self-led training rather than participating in a classroom setting as previously described, or as a supplement to classroom training. Additional functionality has been built into ULW Latent Editor to

facilitate self-led training opportunities. The Latent Editor Training menu contains a new option that allows a user to load multiple files to compare against their current work.
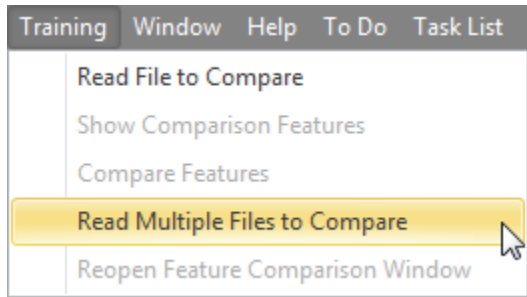
Figure 14 - Self-led training in Latent Editor

Loading multiple files in this way will open a second instance of the Latent Editor application in which the selected files and the examiner's in progress work will be loaded as an overlay on a single image. This allows an examiner to compare themselves against available markup files without interfering with their work, giving them access to the same tools made available to instructor users. Individual users also have the option of creating their own data sets, lessons, and sessions, where they may act as the instructor and student user to facilitate self-led training from within Transaction Manager as described in Section 2.1.1. Though this may not offer the same benefits as training led by an instructor, ACEware does not prohibit users from experimenting with their own personal data sets and lessons.

2.2   Datasets

The lack of sufficient research data is a major limitation to research, the development of new technology, and informed policy decisions in forensic science. In both forensic science and biometrics, datasets are necessary to conduct research and evaluations: to develop and test new technology, to evaluate human factors, and to provide a basis for data-driven policy decisions. Current research is impeded due to a limited quantity of appropriate research datasets. The Forensic Science and Standards Act of 2014 (Senate legislation S.2022, aka the "Rockefeller bill", currently in committee), section 6, if passed will direct NIST to collect and provide such datasets.

ACEware was developed to facilitate the development of standard datasets for training and evaluation. ACEware provides users with

- A specification for friction ridge datasets that seeks to standardize the association of images and features for both latent and exemplar prints. The intent is to propose a standard specification for friction ridge datasets that can be used in the creation and dissemination of future datasets (see Appendix A: Data Set Directory Specification).
- Tools for creating datasets in accordance with the dataset specification. These tools can be used within agencies, for example to collect image pairs that resulted in errors or conflict among examiners for use in future training.
- The NIST SD27/ULW Groundtruth/ELFT-EFS Public Challenge dataset, and Noblis Multi-Latent Dataset formatted in accordance with the dataset specification.

The need for a specification to define the associations between files may not be initially obvious. For a dataset in which the only associations are between each latent and a single specified exemplar image, such a specification may be unnecessary. However, associations become more complex for datasets (such as the combined SD27/ULW Groundtruth/ELFT-EFS Public Challenge dataset) with multiple latents per subject, multiple sets of exemplars per subject, and multiple markup files per latent.

ACEware has added the ability to create and manage data sets from within ULW Transaction Manager. By creating data sets in Transaction Manager, users can import individual files, ranging from images to ANSI/NIST compliant file formats, into a selected data set row. Users may also choose to import an entire standard dataset formatted in accordance with the dataset specification. These import options are shown in Figure 15.
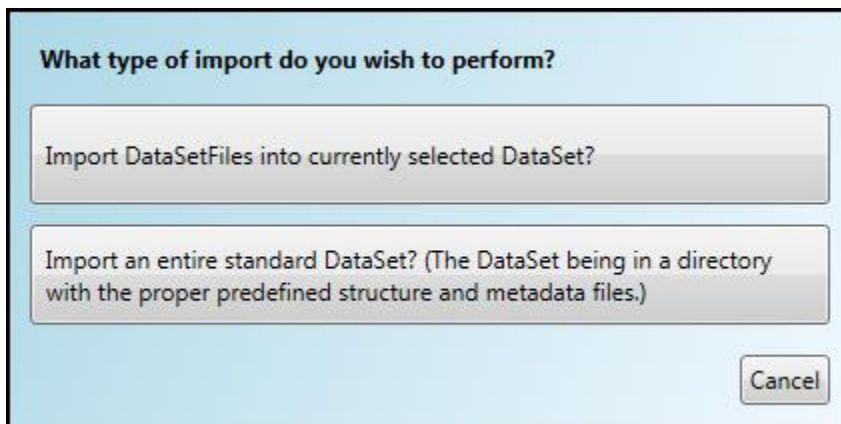
Figure 15 - Data set import options

Data sets created or imported in ACEware will be displayed in the Data Sets panel, as seen in Figure 16, for management by one or more users. Data sets may also be shared among users via the Groups feature described in Section 2.1, and serve as the basis for Lesson content.

Figure 16 - Data browser containing multiple data sets

File "relationships" can also be set within the user interface to create associations among various image and ANSI/NIST files. For example, associating a search to image file means that Search file X contains the markup for latent print Y. Relationships display as tooltips when hovering over relationship set icons as seen in Figure 17 and Figure 18.

Figure 17 - Single data set relationship tooltip

Figure 18 - Multiple data set relationships tooltip

2.3   Comparing and combining minutia markup

Examiners often differ in the minutiae they mark.[29] ACEware incorporates functionality to compare the markup on a single latent print by multiple examiners, or to create a single "voted" markup based on multiple examiners. This ability may be used for training, operational casework, or research:

- For training, this allows students to be compared against an "ideal" markup, or against each other.
- For training or research, this allows the development of "ideal" markup for datasets based on the consensus of multiple expert examiners.
- For operational casework, this permits
  - o Comparing an examiner's Analysis markup and Comparison markup in order to assess if there are indications of excessive changes (extensive additions and deletions of features between Analysis and Comparison may be an indicator that the examiner was biased by the exemplar during Comparison[30]).
  - o Comparing the markup of an examiner and a verifier as part of conflict resolution (when the examiner and verifier reach different conclusions).
  - o Creation of a consensus markup among multiple examiners for courtroom presentations for important cases.

Initial feedback from ACEware testers is that several of these uses are expected to be valuable.

ACEware implements a hardened version of an algorithm initially developed for use in research in the FBI Lab/Noblis *Interexaminer variation of minutia markup on latent fingerprints* study,[31] which describes the algorithm in this way:

> *Here, we use a commonly-used data clustering algorithm, Density-Based Spatial Clustering of Applications with Noise (DBSCAN), to classify minutiae marked by multiple examiners as representing the same minutia on the latent. The DBSCAN algorithm was parameterized with a reachability distance of 0.38mm (0.015 inch)[32]; any marked minutiae within this distance of one another coalesce into a cluster (a cluster starts with an arbitrary marked minutia, grows to include any other marked minutiae (from all examiners) within that distance, and then iteratively grows to include any other marked minutiae within that distance of the cluster). As detailed in Appendix SI-4, small changes to the reachability parameter had a large effect on the total number of resulting clusters, especially with respect to singletons (clusters containing only one marked minutia). The distance of 0.38mm was selected after extensively reviewing the algorithm's performance over a range of reachability settings. After performing this initial clustering, we then identified a relatively small number of clusters that had*

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[29] *[Ulery16, Swofford13]*

[30] *[Ulery14b]*

[31] *[Ulery16]*

[32] *The distance between ridges varies within an impression and between subjects, but average peak-to-peak distances are reported as varying between 0.43mm and 0.56mm [Hicklin13, Ashbaugh].*

grown excessively large: for example, a single minutia mark located between what would otherwise have been two distinct ridge event locations would cause those two clusters to coalesce. These "overgrown" clusters were split using agglomerative hierarchical clustering to produce the final set of clusters for analysis.

For each fingerprint, the set of all minutiae x,y coordinates (as marked by the examiners) was preliminarily clustered using DBSCAN with a given radius r, and no lower limit to the cluster size. That is, singletons were treated as valid clusters, not labeled as "noise."

The implementation of Density-based spatial clustering of applications with noise (DBSCAN) we used was written by Michal Daszkyowski of the University of Silesia in 2004. The DBSCAN radius was set to 0.015" (0.38mm) after extensively reviewing the algorithm's performance over a range of radius settings. In our review, we considered several standard clustering performance measures and visually assessed the resulting clusters as plotted superimposed over the latent prints. Any choice of radius substantially biases the reproducibility distributions: increasing the radius increases the measured mean reproducibility, and decreases the measured number of clusters. We selected a slightly large radius in order to aggregate some of the less precisely focused clusters; we then split many of the oversized clusters in the second step.

Oversized preliminary clusters were split using agglomerative hierarchical clustering, with ceiling (mean number of marks per examiner) as the cutoff point. Hierarchical clustering assembles a tree of cluster relationships; there is no assumption of a fixed radius.

Oversized preliminary clusters were selected for subsequent splitting by agglomerative hierarchical clustering based on a criterion of (mean number of marked minutiae per examiner) > 1.5. This arbitrary threshold was selected because (1) automated splitting of clusters meeting this criterion was highly successful, and (2) for lower values (between 1 and 1.5), it was usually not apparent even to a human how to split correctly without careful interpretation of the fingerprint image. The oversized preliminary clusters often contained multiple, clearly distinct ridge events; most of the remainder were difficult to resolve by visual inspection. We used MATLAB's implementation of agglomerative hierarchical clustering algorithm; Ward's method was selected for computing the distance between clusters. Ward's method helps overcome the main flaw of DBSCAN, which is that it tends to fail when faced with highly heteroskedastic data (data in which the variance differs among subsets).

By loading multiple sets of markup on to a single latent image, we're able to directly compare each set of markup against the other, toggling the visibility of the markup on and off to view markup on a one-to-one or one-to-many basis. Figure 19 shows five sets of markup selected for viewing, some of which may be difficult to see due to the close proximity of other markup sets. By selecting different rows, or toggling feature visibility on and off, more difficult to locate features can be seen with greater clarity as those features are brought to the front of the overlay.
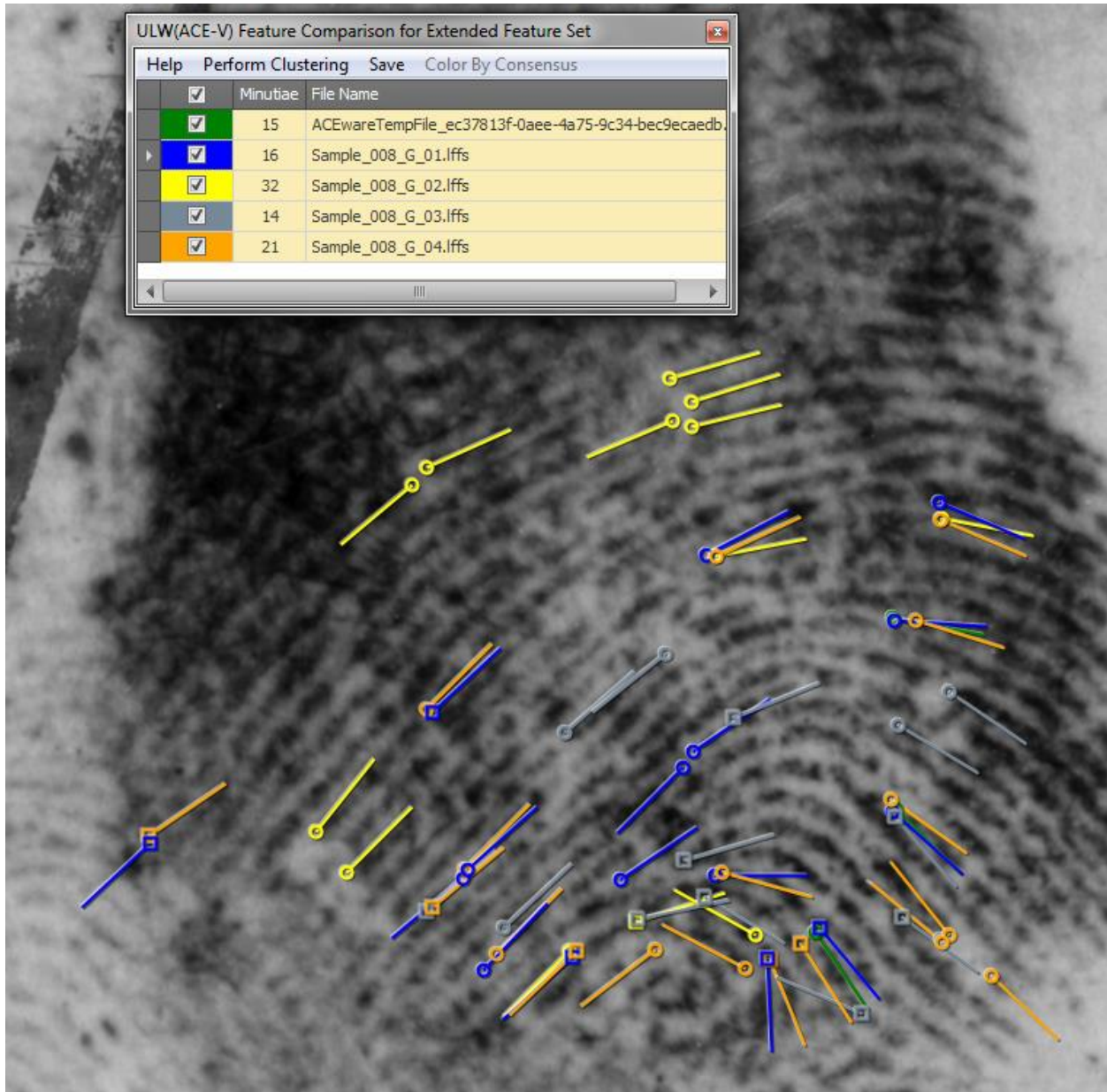
Figure 19 - Five sets of markup viewed as an overlay on a single latent image

The concept of comparing multiple sets of markup on a single latent image is one use-case of comparing and combining markup. As previously noted, this functionality may also be used to create "ideal" markup based on multiple expert examiners. Continuing with the example markup in Figure 19, Figure 20 shows a menu containing various combinations of clusters for generating and displaying "ideal" markup.
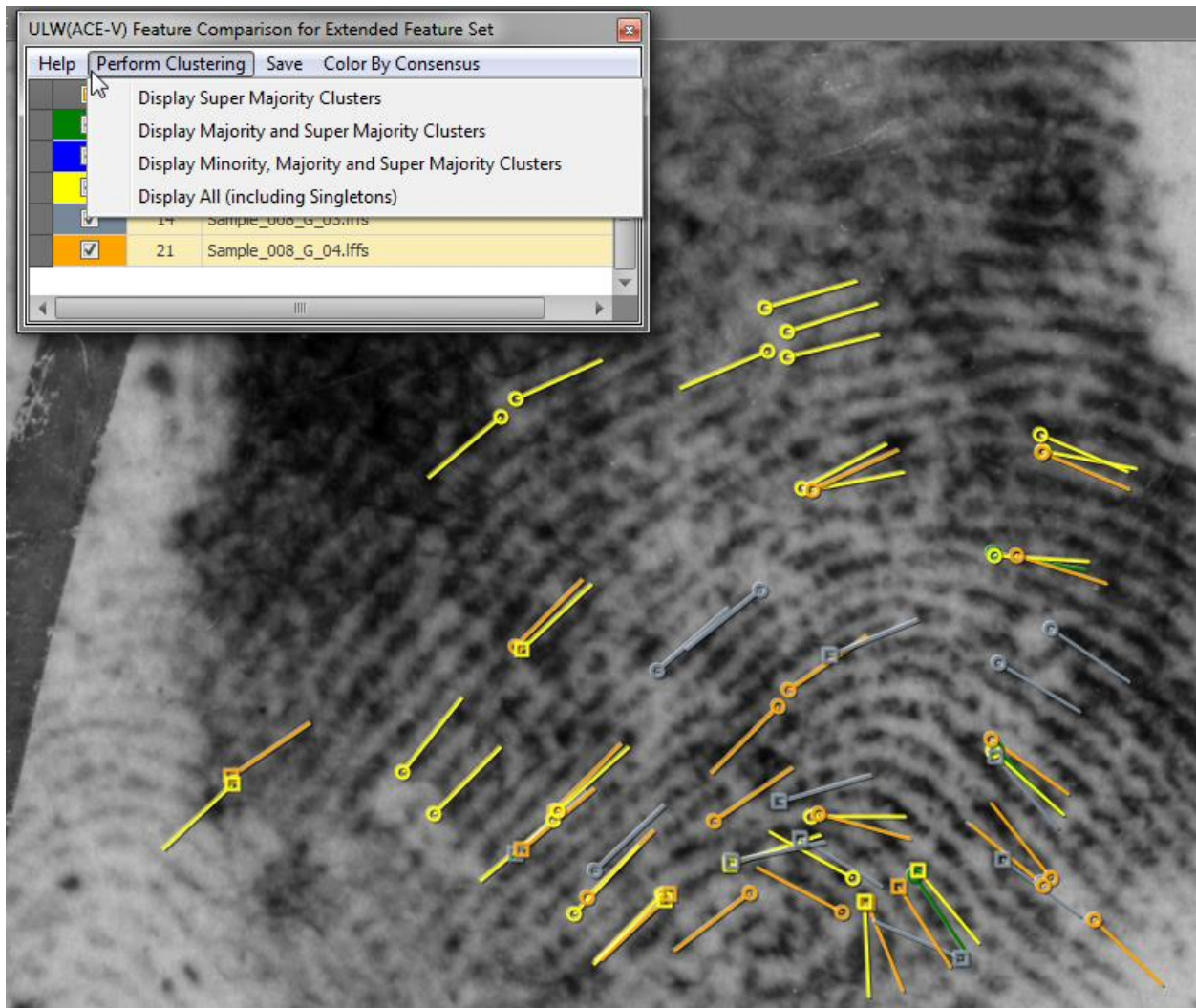
Figure 20 - Clustering options

Clusters are split into four categories:
- **Super majority** clusters are composed of features in which consensus was found among 75% or more of the analyzed examiners
- **Majority** clusters are composed of features in which consensus was found among less than 75% but more than 50% of the analyzed examiners
- **Minority** clusters are composed of features in which consensus was found among less than 50% but more than 1 of the analyzed examiners
- **Singleton** clusters are composed of features in which only 1 examiner marked that feature

As an example, Table 1 shows a possible distribution of clusters based on a number of analyzed examiners and the consensus among those examiners. When clustering markup from five examiners, it would be expected that consensus among four or more examiners would comprise super majority clusters, consensus among three examiners would comprise majority clusters, consensus among two examiners would comprise minority

clusters, and markup with no consensus, meaning only one examiner marked a particular feature, would comprise singleton clusters.

	Super Majority	Majority	Minority	Singleton
# of Examiners				
3	3	2	-	1
4	4	3	2	1
5	4+	3	2	1

Table 1 - Sample cluster distribution

Using ACEware's minutia clustering algorithm, we're able to analyze the selected examiners' markup and display feature clusters according to the option selected in the Perform Clustering menu shown in Figure 20. Users are able to select different combinations of markup and view different combinations of clusters until the desired outcome is achieved. Figure 21 shows the results of displaying super majority clusters based on the previously selected five sets of markup.
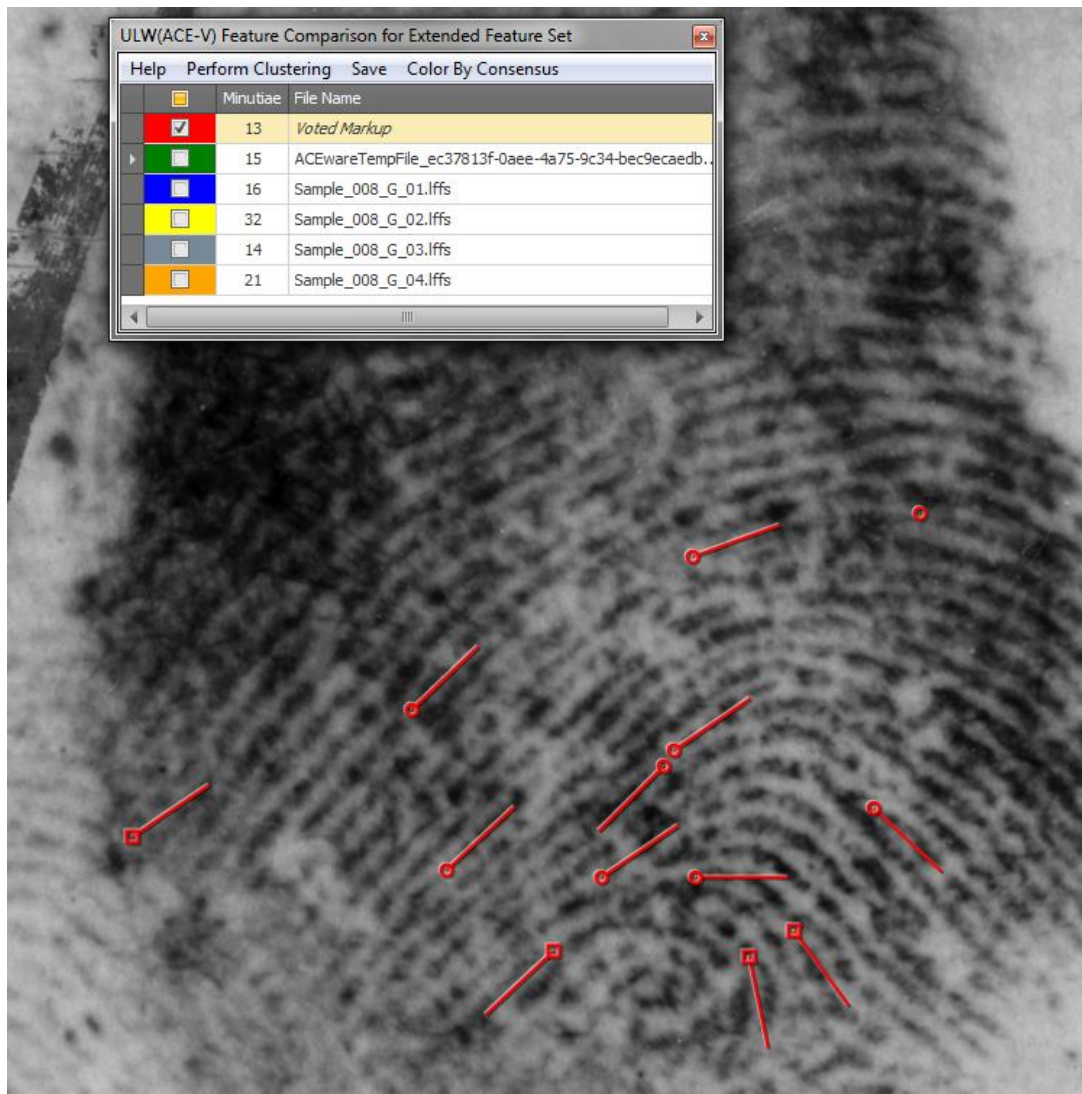
Figure 21 - Voted markup results only

22

The results of markup clustering can be saved to an LFFS file for future use in training or research. Also available is the option to save the clustering results, as well as the selected sets of markup, to the EFS defined ASYS file for future analysis and exchange between organizations.

For comparison, Figure 22 shows the voted markup results in addition to all of the markup that went into creating those results. Due to the close proximity of the visible markup, some features are hidden or otherwise difficult to see.
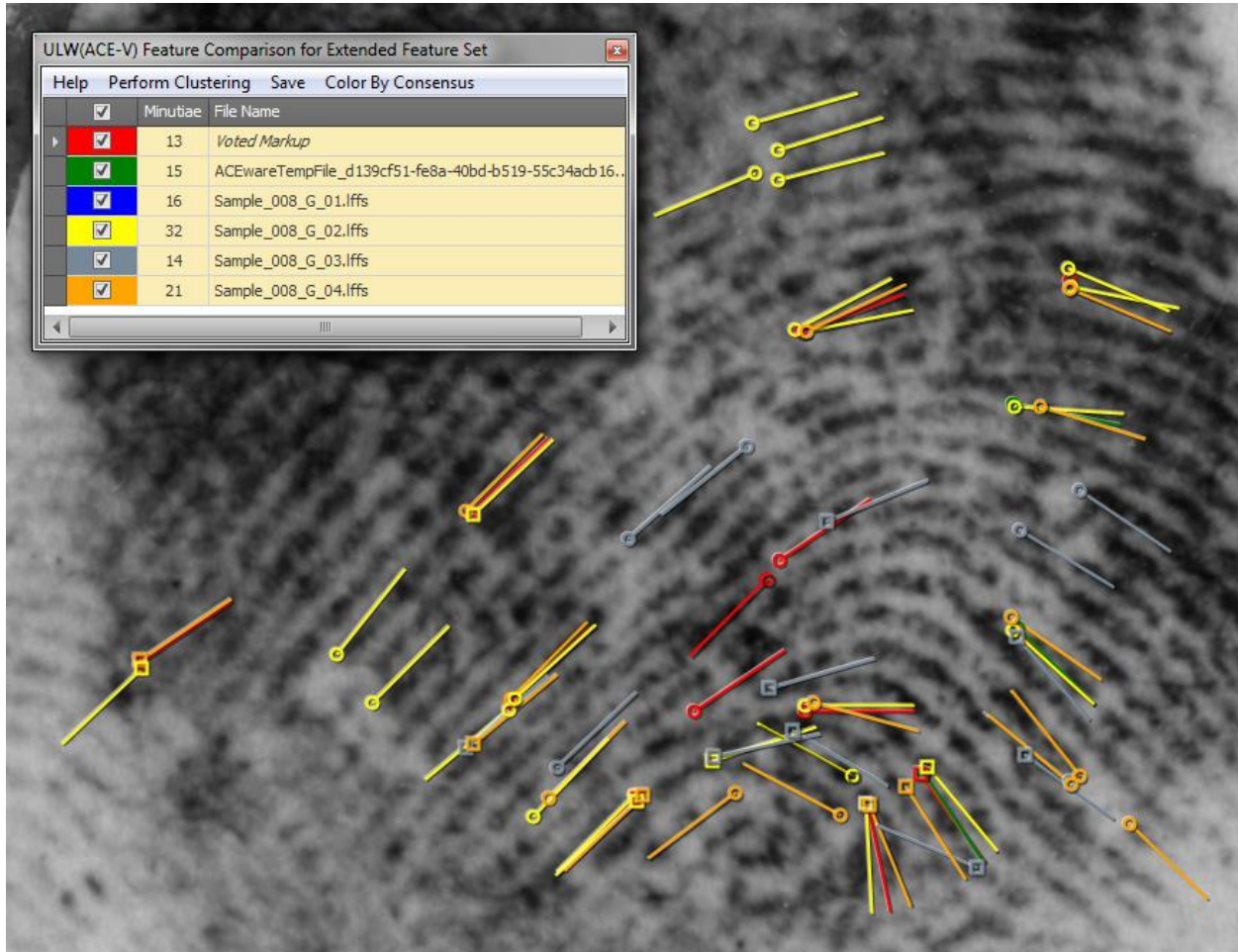
Figure 22 - Voted markup results with additional markup

From the examples in Figure 19, Figure 21, and Figure 22, we can start to see how different combinations of markup, and different levels of clustering, can help create a combined set of potential "ideal" markup. To further understand how individual features are factored into the results of minutia clustering, we can switch our view from coloring features based on individual files to coloring features based on consensus levels by selecting the **Color by Consensus** option. Figure 23 shows the same markup displayed in Figure 19, colored by consensus rather than by file. In this view, we can now see the individual features that were factored into producing the results of the super majority cluster results seen in Figure 21, specifically. Had a clustering option other than super majority been selected in the

examples above, we could expect to see clustering results based on features displayed in yellow (majority clusters), orange (minority clusters), and even red (singleton clusters).
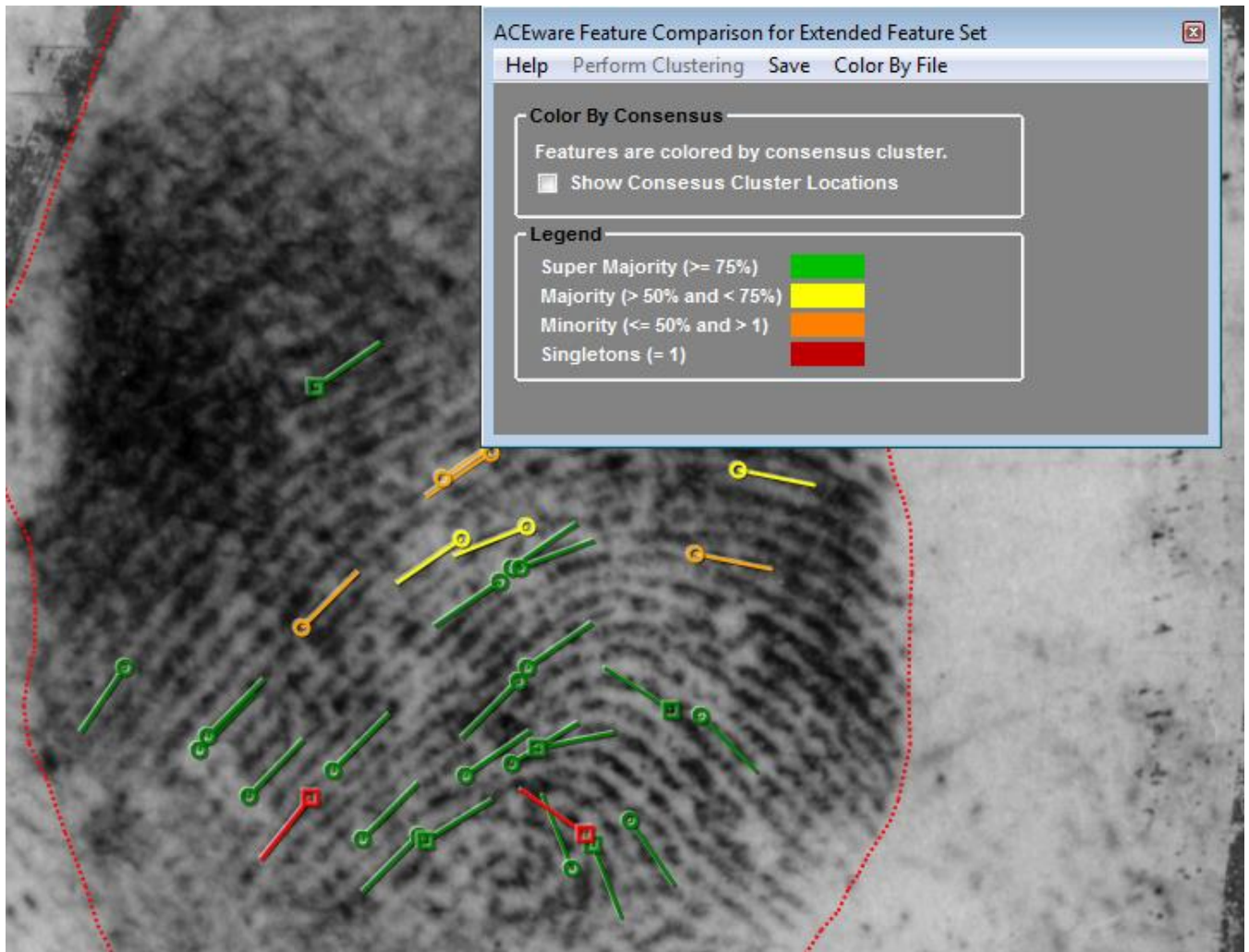
Figure 23 - Markup colored by consensus

Feature comparison and combination through clustering is available through ACEware's data set based Training functionality and through Latent Editor's Training menu, as detailed in section 2.1.

2.4   Enhancements to enable non-AFIS casework

ULW already has extensive AFIS-specific functionality, much of which is appropriate for non-AFIS casework. A small number of relatively minor enhancements to ULW have made ULW more useful for non-AFIS casework.

2.4.1   Verifications

As part of ACEware's goal to support the ACE-V process, the ability to perform verifications from within the ULW software has been introduced.

As seen in Figure 24, administrative users are presented with the option of selecting a combination of blind or non-blind verification methods, with neither or both options as

viable selections. Each verification method is selected for each possible determination, or comparison conclusion, that can be set within the ULW Comparison Tool. In a blind verification, the original examiner's markup and conclusion are removed and the verifying examiner is given only the latent print and a single candidate exemplar; in a non-blind verification, the verifying examiner is given a copy of the original examiners' work, including all marked features and conclusion, in order to review the work performed.
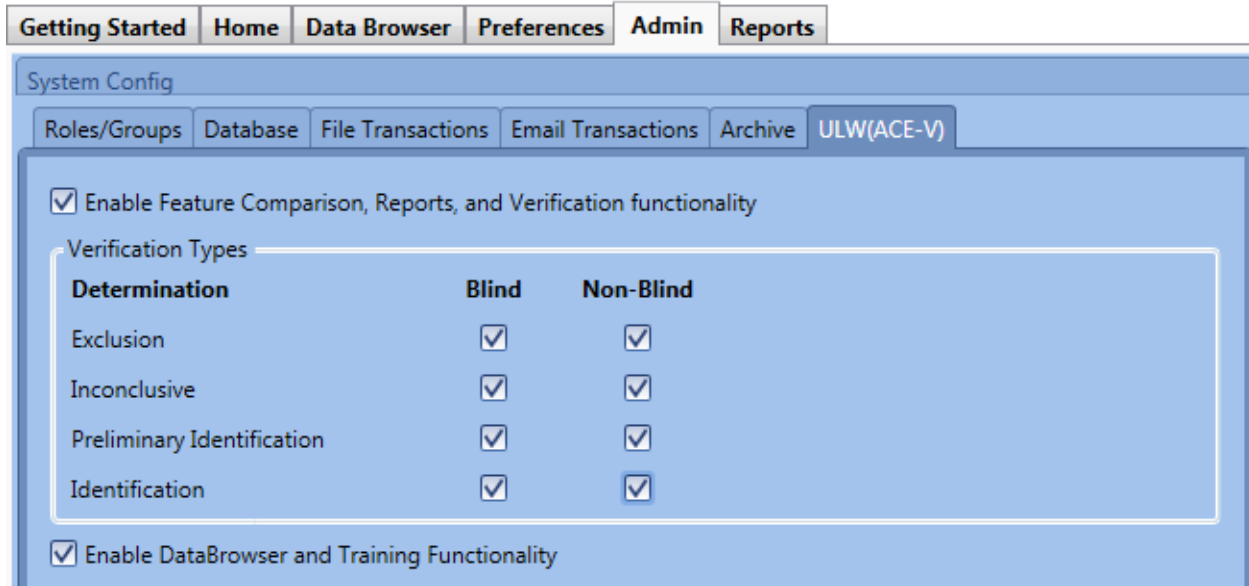
Figure 24 - Verification configuration

For determinations with no option selected, no verification will be created as a result of selecting that determination in Comparison Tool. Determinations with a single option selected will automatically generate a verification of that type while determinations with both options selected will prompt the user to select a verification method upon verification assignment.

When an examiner compares a latent print search against potential exemplar candidate matches within the Comparison Tool, each determination requiring verification made by the examiner will cause the Verifications count in the Transaction Manager User Data Grid to increase. Figure 25 shows an example in which three verifications have been created for case B_118_0_1, noted in the Verifications column. This column is only seen by administrative users and serves as a flag indicating a need for verifications to be assigned and monitored.

Archived	Prefix	Case ID	Ext (...	Latent#	Search	Edited	Submitted	In ULF	SRL	IRQ	IRR	ULM	ERRL	Verifications
☐						☐	☐	☐						
☐	B	118	0	1	LFFS	☑	☑	☐	1	1	0	0	0	3
☐	B	118	0	2	LFIS	☐	☐	☐	0	0	0	0	0	0

Figure 25 - Verifications count

Verifications can be assigned to another examiner from within the Verification preview panel, accessed by clicking on the Verification count for a particular case. When assigning verifications, administrative users are presented with a list of possible assignees based on the user accounts created in Transaction Manager. In the event both blind and non-blind verification methods were selected for the determination in question, users will be required to select both an assignee and a verification type to complete the assignment process, as seen in Figure 26.
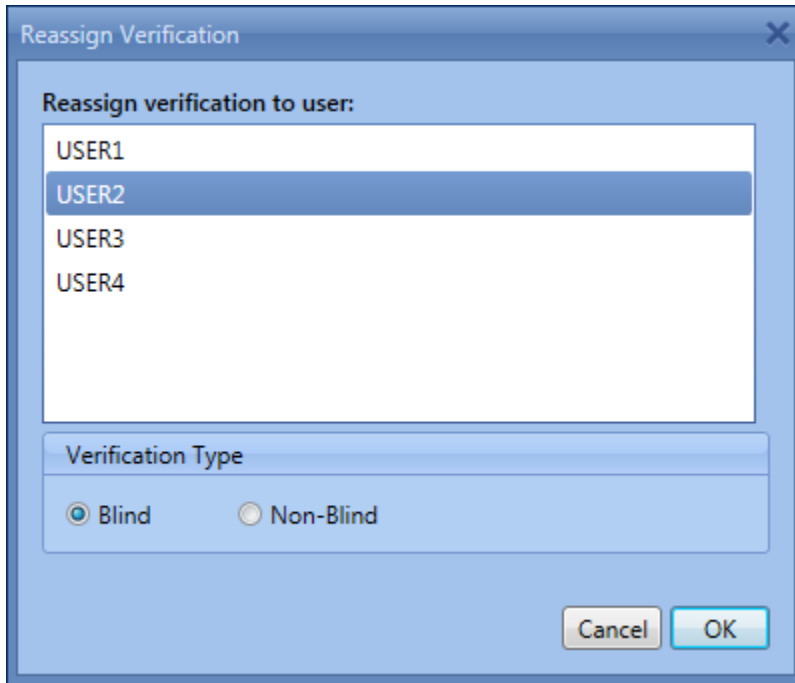
Figure 26 - Assigning verifications

When a verification is successfully assigned, the assignee receives a new task in his or her Task List as shown in Figure 27; these tasks are accessible from ULW Transaction Manager, Latent Editor, and Comparison Tool. Verification assignments are kept separate from the verifying examiners casework and act as single events in which examiner action is needed.
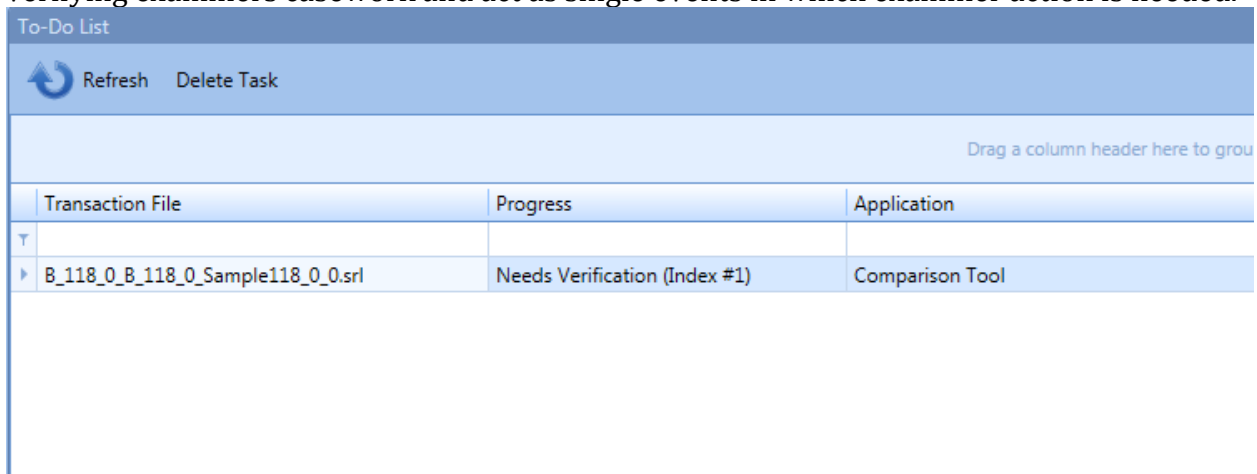
Figure 27 - Verification task

Verifying examiners can open an assigned verification by double-clicking on the task to open the appropriate file and perform the necessary level of verification. Upon completion, verifying examiners may save their work and the verification is complete. Both the original examiners work and the verifying examiners work are stored as separate COMP files within Transaction Managers Transaction folder to maintain the work performed by each examiner. After a verifying examiner completes the verification process, the original examiner and the verifying examiner's determination will be compared and the status of the verification will change to one of three potential options:

- **Verified** is a result of the original examiner and verifying examiner marking the same determination
- **Conflict** is a result of the original examiner and verifying examiner reaching dissimilar conclusions, for example Exclusion vs. Inconclusive
- **Critical Conflict** is a result of the original examiner and verifying examiner reaching dissimilar conclusions, for example Exclusion vs ID/Preliminary ID (and vice versa); this level of conflict may pose significant risk if not evaluated and is therefore flagged as critical.

Candidate Index		File Name	Current Assignee	Original Examiner	Status	Original Determina...	Verification Date	Verification Type	
	1	B_118_0_B_118_0_S...	USER2	USER1	Critical Conflict	11/22/2016 12:11:0...	11/22/2016 1:25:07...	Blind	
	2	B_118_0_B_118_0_S...	USER2	USER1	Verified	11/22/2016 12:11:0...	11/22/2016 12:12:4...	Non-Blind	
	3	B_118_0_B_118_0_S...	USER2	USER1	Conflict	11/22/2016 12:11:0...	11/22/2016 12:13:2...	Non-Blind	

Figure 28 - Completed verification statuses

In the event any conflict status is generated, administrative users may begin a conflict resolution process.

2.4.2 Individual feature annotations

Understanding an examiner's thought process or rationale for marking particular features is a useful tool in determining whether sufficient detail has been provided in the latent print examination process. ACEware introduces a new **Enter Comment** option when examiners right-click on points marked in Comparison Tool, shown in Figure 29.
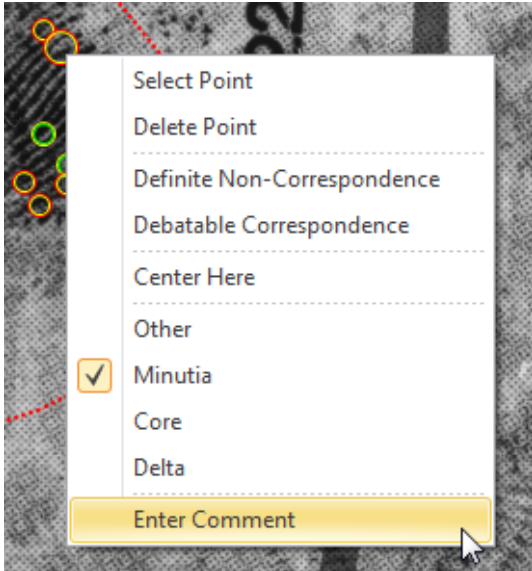
Figure 29 - Enter comment option in Comparison Tool

By selecting the **Enter Comment** option, examiners are presented with a blank, free text form in which comments about that particular feature can be entered.
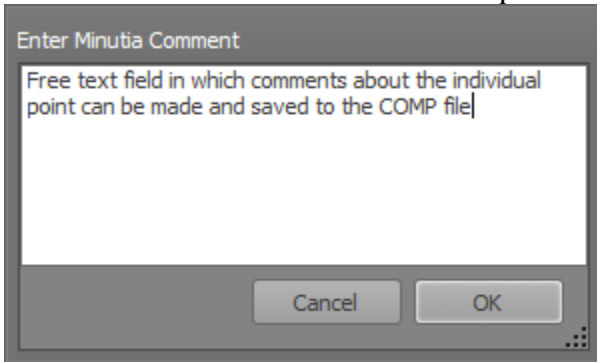
Figure 30 - Commenting on individual features

Entered comments will then display when examiners hover over a point for which a comment has been made.
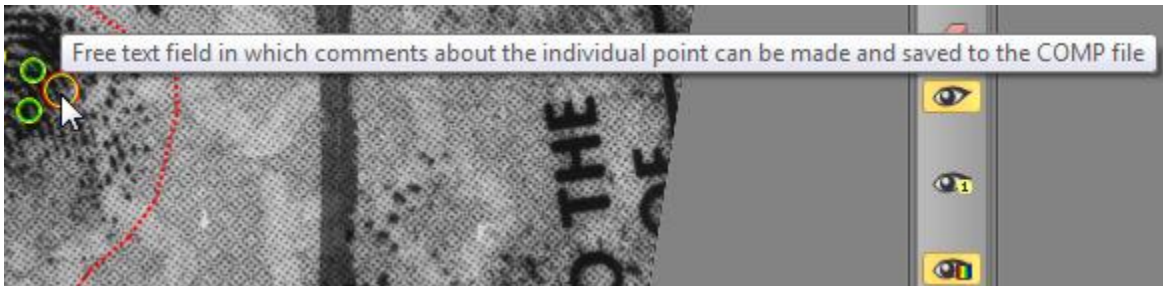
Figure 31 - Viewing a feature-level comment

Individual comments are viewable by verifiers in non-blind verifications and may be used to better understand an examiner's rationale for individual feature markings.

2.4.3   Quality assurance reports

One of the key implications of standardized feature markup is that it would enable automated quality assurance (QA). As part of ACEware we implemented a limited amount of QA reporting — both as useful tools, and as examples of what automated QA could be possible.
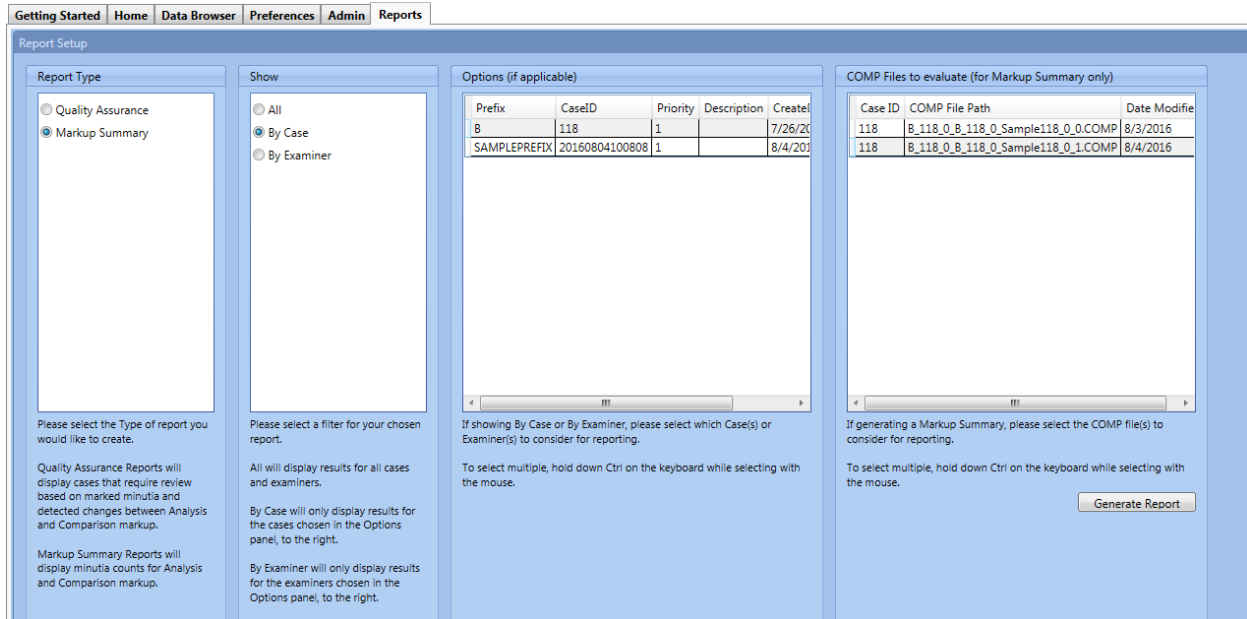
Figure 32 - Reports tab in Transaction Manager

Under ACEware, ULW Transaction Manager now has Quality Assurance Reports, which list those cases that require "review" or "rigorous review" based on marked minutiae and detected changes between Analysis and Comparison markup:[33]

- Rigorous Review: Identifications where fewer than 7 minutiae were marked, or where fewer than 7 minutiae were retained between Analysis and Comparison
- Review: Identifications where fewer than 12 minutiae were marked, or where fewer than 12 minutiae were retained between Analysis and Comparison

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[33] *The 7- and 12-minutia thresholds are based on the results of the White Box study [Ulery14a].*

QUALITY ASSURANCE REPORT

Date Generated: August 4, 2016
Number of Latent Print Searches: 2
Case ID: 118
Examiner: All

FOR RIGOROUS REVIEW

Case ID	Latent #	COMP File	Examiner(s)	Issue
118	2	N/A	WILL	< 7 minutia marked

FOR REVIEW

Case ID	Latent #	COMP File	Examiner(s)	Issue
118	1	N/A	WILL	< 12 minutia marked
118	1	B_118_0_B_118_0_Sample1 18_0_0.COMP	WILL	<12 Retained minutia between Analysis and Comparison

Figure 33 - Quality Assurance Report example

Markup Summary Reports display the distribution of features with respect to the examiners' assessments of value and comparison conclusions.

MARKUP SUMMARY REPORT

Date Generated: August 5, 2016
Number of Latent Print Searches: 10
Number of Candidates: 10
Case ID: All
Examiner: All

ANALYSIS

Assessment of Value	Number	# of Analysis Minutia				
		Minimum	Q1	Median	Q3	Maximum
Value for ID	6	8	11	15	21	23
Limited Value	1	11	11	11	11	11
No Value	3	5	6	8	11	14
Undetermined	0	0	0	0	0	0

COMPARISON

Determination	Number	# of Corresponding Minutia				
		Minimum	Q1	Median	Q3	Maximum
Individualization	4	12	14	17	18	23
Inconclusive	2	10	13	16	19	22
Exclusion	4	8	9	12	13	16
No Conclusion	0	0	0	0	0	0

*Italicized numbers indicate calculated values rather than actual minutia counts

Figure 34 - Markup Summary Report example

2.4.4 Expansion of EFS fields

Expanding ULW's support of the extended feature set, Comparison Tool now has access to several EFS fields such as Latent Substrate, Latent Matrix, Latent Processing Method, Method of Feature Detection, Evidence of Fraud, etc., that were previously only available in Latent Editor. Adding support for these fields in Comparison Tool gives examiners an opportunity to refer to EFS data during comparison, or to enter EFS data if it does not already exist, thereby expanding the boundaries of detailed documentation.
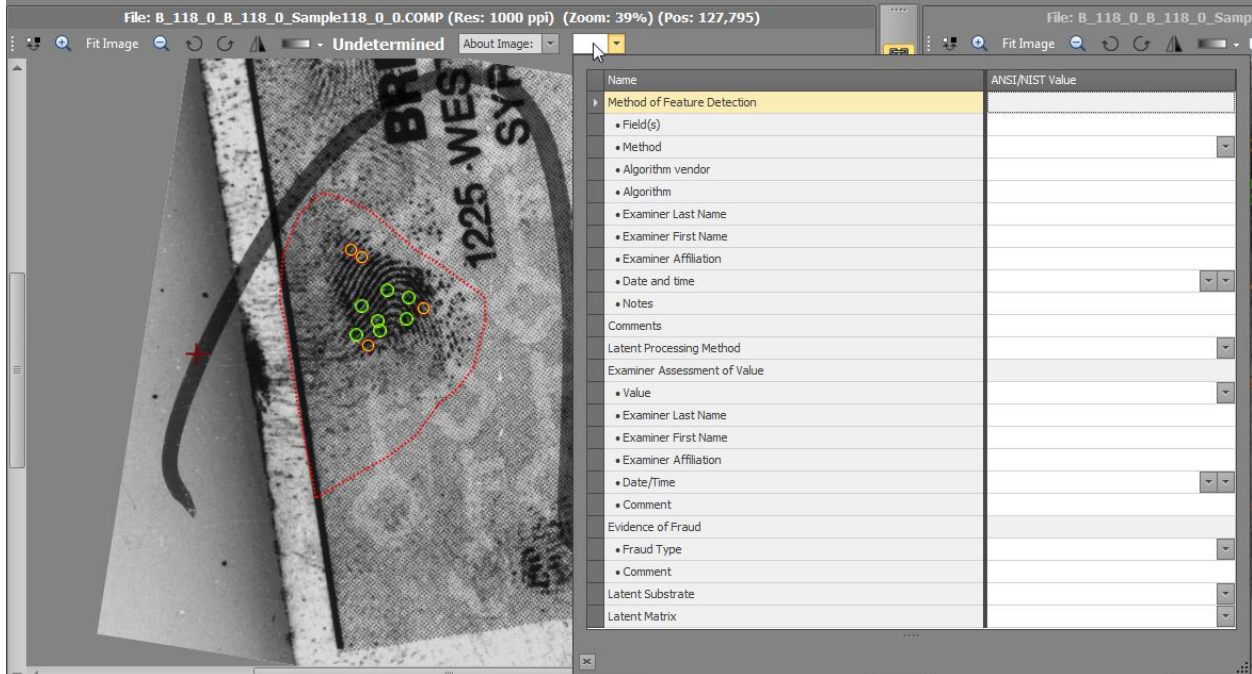
Figure 35 - Blank EFS Fields in Comparison Tool

Any data entered during comparison is saved to COMP files for record keeping and data exchange between organizations.

3 Dissemination

The purpose of this project is to deliver software and work with agencies to ensure its adoption. The project involved collaboration with the law enforcement agencies that were our official partners (Fairfax County Police Department, New York State Division of Criminal Justice Services, and Arizona Department of Public Safety Crime Laboratory), as well as additional testers (FBI Laboratory, Royal Canadian Mounted Police, and Cuyahoga County Regional Forensic Science Laboratory). The partners and testers provided input on initial requirements as well as assisted with the refinement of requirements.

An Alpha test version was released for feedback in January 2015. Beta test versions were released in March 2015, late November 2016, and early December 2016.

In depth demonstrations of functionality provided to multiple organizations (including FBI Lab, Cuyahoga County Regional Forensic Science Laboratory, Fairfax County Police Department, New York State Division of Criminal Justice Services, Arizona Department of Public Safety Crime Laboratory) provided a means for obtaining immediate feedback for new requirements or improvements/modifications to existing requirements based on organizational needs. These demonstrations also provided beta testers with an opportunity to attain basic familiarity with ACEware features to help ease the transition into testing.

The November/December 2016 Beta test version of ACEware, named *ULW with ACE-V Enhancements*, was provided after functional demonstrations to give testers an opportunity to get hands on experience with a version of the software that was considered feature

complete. Feedback from demonstrations and beta testing directly impacts the need for the final release, prior to the conclusion of the project as well as the content of those releases.

Other ACEware presentations have been given in the form of conference briefings, including:

- American Academy of Forensic Sciences 68th Annual Scientific Meeting in Las Vegas, NV - February 2016
- International Association for Identification 101st International Forensic Educational Conference in Cincinnati, OH - August 2016

4   Conclusions

4.1   User feedback

The reactions to the ACEware functionality have been positive with users noting multiple use cases where ACEware would either improve current processes or introduce new processes that would be beneficial for past, current, and future work.

Many testers believe data set development and management tools introduced by ACEware will provide a platform for compiling and storing casework in a standard format and will act as a valuable tool for retrieving such data for later use. Testers also noted the potential for data set file relationships to serve as a valuable tool in associating data within large cases and may even provide useful tools for assisting in conflict resolution by associating original and verifying examiner data to be tracked both within and outside of the software application. Interest was shown in enhancing data set development tools to support custom relationship options (e.g., same latent image resulting from different lift methods) as well as batch relationship assignment for faster data set file association.

The training functionality introduced by the ACEware project was also very well received with a number of testers seeing great value in the overlay functionality. In one example, testers noted overlays are currently used to facilitate conversations with trainee and active case working examiners but in the absence of latent print specific tools, third-party programs such as Photoshop are necessary to produce useful results, a process which can take hours depending on the number of examiners involved. With ACEware, overlays can be created in a fraction of the time. Testers were also interested in the possibilities afforded by data set driven training with the ability to create reusable lesson plans for training examiners on special cases (e.g., distortion, scars, or digital artifacts) and image processing techniques (e.g., tonal reversal).

Quality assurance reporting features were generally well received though many testers showed an interest in more generalized reporting capabilities such as the ability to select from a list of available data points to generate a simple output of all data related to cases within the Transaction Manager tool. However, other testers noted the potential for quality assurance reports to provide a basis for returning to files previously submitted to the Unsolved Latent File (ULF) for further analysis and potential re-submission in an effort to lower the number of searches submitted to and retained in the ULF. Testers also saw value in using the quality assurance reports to gauge the effectiveness of individual examiners and identifying areas where additional training may be necessary or valuable.

ACEware's verification features received favorable reviews overall though feedback to date suggests additional work is necessary to offer a more robust solution that fits the various needs of multiple organizations. While the ACEware verification functionality has room to grow, feedback also indicates ACEware introduces basic verification procedures that can be adopted by organizations that do not yet have a standard verification process in place, increasing the use of standard ACE-V processes.

For specific comments and enhancement suggestion, see [Appendix B: Compliments and Enhancement Suggestions](#).

4.2   Impact

4.2.1   *What is the impact on the criminal justice system?*

Whether, or how, latent print examinations are documented in detail greatly varies among agencies in the criminal justice system. ACEware seeks to provide improved documentation tools; training on standardized, detailed documentation practices; and enhanced latent print examination tools that support conflict resolution, quality assurance, and verification of latent print examiner work. By making these tools readily available to state, local, and federal agencies, ACEware will help increase the rigor applied to the examination process in an effort to decrease the risk of false or missed identifications.

4.2.2   *How has it contributed to crime laboratories?*

ACEware will contribute to the improvement of detailed latent print examination documentation through the training of standard latent print markup and documentation practices; improved latent print examination tools; and adherence to pre-existing standards that support rigorous documentation, data exchange, and long-term archiving.

4.2.3   *What is the impact on technology transfer?*

ACEware expands on the Universal Latent Workstation software. Enhancing and adding to the capabilities of pre-existing, widely used software, will have an immediate impact on users by providing new tools in familiar applications. While adoption rates may vary among agencies, those that do incorporate ACEware into daily operations will help build a baseline for detailed documentation practices that will be consistent across participating agencies.

4.3   Implications

Beyond the specific functionality implemented in ACEware, adoption of ACEware is intended to improve the rigor, transparency, standardization, and quantifiability of the latent print examination process:

- Provide a standardized approach for applying the ACE-V method, building upon SWGFAST standards and EFS
- Facilitate increased consistency and proficiency in feature selection and detailed documentation by latent print examiners
- Improved resolution of disagreements between examiners and verifiers (conflict resolution)
- Standardize formats for data exchange, long-term data archiving, and evidentiary presentations
- Provide a standard platform for collection of data and performance metrics

- Provide a basis for quantitative analyses of latent print examination, including automated metric-based quality assurance, and quantitative examiner performance evaluations

After the release of ACEware and completion of the development phase, future research can evaluate its effectiveness, and develop additional quantitative analyses of latent print examination.

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6 Appendix

6.1 Appendix A: Data Set Directory Specification

Purpose
The purpose of the Data Set Directory Specification is to define a file format and structure for the development of standardized friction ridge data sets that enables data formatting to be recognized across multiple jurisdictions to increase the potential for data exchange in support of training or research.

Data Set Directory Structure
The DataSet directory must conform to the hierarchy as shown below. If there are no relevant files for a particular directory or subdirectory (e.g., no files to place in the ANFiles folder) the directory or sub-directory may be omitted.

- Datasets
  - Dataset Name (e.g. SD27)
    - ANFiles
      - CandLists
      - Comps
      - LatentANs
        - LatentAN-Image
        - LatentAN-ImageMarkup
        - LatentAN-Markup
      - SubjectANs
        - SubjectAN-Set
        - ExemplarAN-Image
        - ExemplarAN-ImageMarkup
        - ExemplarAN-Markup
    - Images
      - ExemplarImages
      - LatentImages
      - OriginalImages
    - Documentation
    - References.txt
    - InheritedData.txt
    - Subjects.txt
    - InheritedSubjects.txt
    - Metadata.txt
    - Xref.txt
    - Ver_NAME__DATEorVNum.txt

As an example, the following image shows a folder structure based on the structure outlines above. The left side of the image displays the hierarchy of folders while the right side of the image displays the contents of the root *SampleDataset* folder.
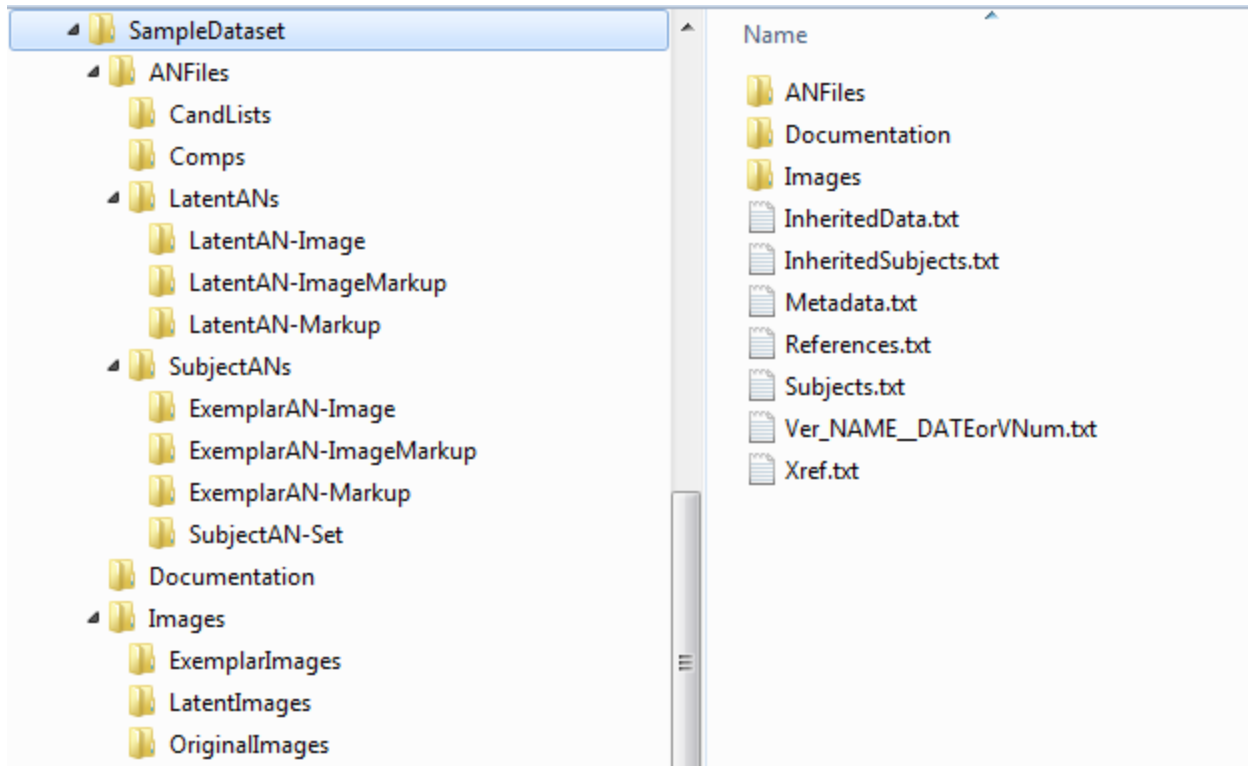
Figure 36 - Graphical View of Data Set Directory Hierarchy

Data Set Directory Descriptions

Datasets
Root of directory tree, must always be present.

Dataset Name (e.g. SD27)
This is one data set's directory. Files that are inherited from other data sets are listed in InheritedData.txt, while files that are new or modified from their sources are in Images if pure image files and ANFiles if transaction information is attached. Different subjects with images or AN files in the directory are given unique identifiers and listed in Subjects.txt. Relationships between images, AN files and subjects in the data set are delineated in Xref.txt using the list of possible relationships defined in the comments there. Names must contain no spaces. Only permissible symbols are - and _ (for multiplatform use). Double underscores (__) and double dashes (--) are not permitted. Any files not of the specified types must go in Documentation.

ANFiles
Subdirectories under this directory contain ANSI/NIST files, which include images and/or markup, and possibly other information (e.g. demographics). All files must be valid ANSI/NIST files.

CandLists
Contains AN files with one or more candidates contained in a candidate list, including match scores and other relevant transaction information. SRL files go here. Files always contain images (generally exemplars but sometimes latents); file may contain markup in type-9 record. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

Comps
Contains files with one probe image (sometimes referred to as "the latent," although it may not be the only latent) and one or more candidate images (sometimes referred to as "exemplars," although they may not always be). May contain feature markup, including corresponding points between pairs of prints. COMP format is defined in LITS.

LatentANs
Subdirectories contain AN files with latent images and/or markup. 1 image per file.

LatentAN-Image
Latent AN files that only have images (no markup), i.e. LFIS. 1 image per file. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

LatentAN-ImageMarkup
Latent AN files that have markup AND images. 1 image per file. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

LatentAN-Markup
Latent AN files that only have markup (no images). 1 image per file. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

SubjectANs
Subdirectories contain AN files with Exemplar images, sometimes markup, for ONE person per file (see "Candlists" for multiple people per file). Multiple things related to a single person (i.e. results of an IRR linked to original image to a candidate list).

SubjectAN-Set
Exemplar AN files with images for multiple finger/palm positions, not just the specific position corresponding to the probe latent. Generally contains 14 images (10 rolled + 4 plain). May contain markup (in type-9 records). One subject, multiple finger/palm positions. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

ExemplarAN-Image
Exemplar AN files that have images (no markup). One subject, one image per file. Finger/palm position corresponding to the probe latent.

ExemplarAN-ImageMarkup
Exemplar AN files that have images AND markup. One subject, one image per file.
Finger/palm position corresponding to the probe latent. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

ExemplarAN-Markup
Exemplar AN files that have markup (no images). One subject, one image per file.
Finger/palm position corresponding to the probe latent. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

Images
Directory containing subdirectories of images within a dataset.

ExemplarImages
Exemplar image files that are 500 or 1000ppi and grayscale. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

LatentImages
Latent image files that are 500 or 1000ppi and grayscale. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

OriginalImages
This folder contains images that may be color, various resolutions, may contain background or multiple impressions. (e.g., an image from a crime scene containing several latent prints). When OriginalImages are present, Images in the other directories will reference these as their source. Files may be contained in dataset-specific subdirectories starting with "_" (no spaces, no symbols other than - and _); no further subdirectories are permitted.

Documentation
Any files that are not otherwise specified must go in the Documentation directory. May contain subdirectories or any type of files. A file named README (.txt, .doc(x), .pdf all acceptable) is mandatory.

References.txt
Lists other datasets used, including version. This file is required if InheritedData.txt OR InheritedSubjects.txt is present, and otherwise is not included. No path information is included. Lines starting with # are comments and can be ignored.

InheritedData.txt
Contains path information for data inherited from other data sets. Files included by reference here are treated as if they are fully part of this dataset, and can be included in the Subjects and Xref files. Paths are relative to this directory and always start "../" (e.g.

"../SD27/ANFiles/Comps/L001g.comp"). Paths include forward slashes for platform independence. Lines starting with # are comments and can be ignored.

Subjects.txt
Text file containing the unique subject identifiers for all subjects contained in this dataset. Subject IDs may not contain spaces, cannot be case sensitive (capitalization is permissible but only for clarity); the only permissible symbols are - and _; double underscores (__) and double dashes (--) are not permitted. Each line contains one subject ID and nothing else. Other datasets may refer to these subjects by reference by using the dataset name followed by a double dash (--) followed by the subject ID. This only includes subjects that are not inherited from other datasets: see also InheritedSubjects.txt. {Leading zeroes must be preserved; otherwise sorting and uniqueness when used as a reference across datasets would become broken (e.g. "BDM--001" should not be reduced BDM--1")}. It is recommended that all subject IDs for a dataset be the same length. # may be used on any line to create a comment.

InheritedSubjects.txt
This contains subjects inherited from other datasets. The use is identical to Subjects.txt, but each line starts with a dataset name (that cannot be this dataset), followed by "--" and the subject ID as used in that dataset. The References.txt file must include the name and version of each dataset. (Special case: if this dataset refers to dataset A, and dataset A inherits subjects from dataset B, then this dataset must include a reference to dataset B, and the subject IDs would all be prefixed "B--"). Note that Subjects can be inherited even if the referenced dataset is not present. # may be used on any line to create a comment.

Metadata.txt
Tab-delimited file containing filename, subjectID, and other metadata. Generally all files that contain a single subject will indicate subject (if known). Other columns are optional (they are there to provide a standard means of indicating metadata for image files). Lines starting with # are comments and can be ignored. (See "Metadata descriptions")

Xref.txt
Tab-delimited text containing all known relationships between items in the data set (including items included by reference), using a tab-delineated row of ChildFile, ParentFile, Relationship and (optional) RelationshipDetail. See "Xref descriptions" for detail. # may be used on any line to create a comment.

Ver_NAME__DATEorVNum.txt
Mandatory. The name of this file indicates the version of the dataset. The dataset name (identical to the containing directory name) is followed by a double underscore (__) and a date or number indicating the specific version. Whenever the contents of a dataset are changed, the name of this file must be changed. The contents of this file are irrelevant though it is suggested "Dataset configuration file: do not delete" be included so the file does not appear as empty.

Xref descriptions

The image below details the relationships that may result from files contained within the data set directory. As an example, when viewing the ***MarkupToPrint*** column, files contained within ***LatentAN-Markup*** or ***ExemplarAN-Markup*** will act as the "from" file while files contained in ***ExemplarImages*** or ***LatentImages*** will act as the "to" file. Thus, files from ***LatentAN-Markup*** may have a ***MarkupToPrint*** relationship to files contained within ***LatentImages.***

	MarkupToPrint	LatentToCandidateList	LatentToCandidate	ImageToImageSet	ImageIdentical	MarkupIdentical	SourceToDerivedImage	SameSourceImage	SourceToDerivedMarkup
Permissible relationships in the Xref file									
	from: markup; to: print	*from: latent; to: list of candidates (potential matches)*	*from: latent; to: single candidate (potential match; used to indicate things like close nonmatches)*	*from: single image; to: AN file containing that exact image (among other images)*	*from/to: images are identical in every way (each file contains 1 image)*	*from/to: markup is identical in every way (e.g. special case of associating an LFFS with image to the same LFFS without image)*	*from: source image; to: derived image (e.g. cropped, rotated, compressed)*	*from/to: images came from the same source, e.g. both scans of the same paper photo (each file contains 1 image)*	*from: source markup; to: modified markup (e.g. 2nd examiner modified)*
CandLists		to	to	to					
Comps				to					to
LatentAN-Image		from	from	from	to;from		to;from	to;from	
LatentAN-ImageMarkup		from	from	from	to;from	to;from	to;from	to;from	to;from
LatentAN-Markup	from	from	from			to;from			to;from
SubjectAN-Set				to					
ExemplarAN-Image				from	to;from		to;from	to;from	
ExemplarAN-ImageMarkup				from	to;from	to;from	to;from	to;from	to;from
ExemplarAN-Markup	from					to;from			to;from
ExemplarImages	to			from	to;from		to;from	to;from	
LatentImages	to	from	from	from	to;from		to;from	to;from	
OriginalImages							from	to;from	
Examples	*LFFS to image*	*LFFS to SRL*	*latent to exemplar that was false ID by an examiner*	*LFFS to IRR*	*LFIS to image*	*LFFS with image to the same LFFS without image*	*cropped image to uncropped image*	*image to image*	

Metadata Descriptions

The table below outlines the possible categories that may be used when creating the Metadata.txt file.

Filename	Always starts with "ANFiles/", "Images/", or "../"
SubjectID	Entry from Subjects.txt or InheritedSubjects.txt
Position	Finger/palm/plantar numeric code from AN2011/2013 Table 8. Fingerprints are generally 1-10 if known, 0 if unknown.
Segment	Only used if Position = [0..10]. Alphanumeric code from AN2011/2013 Table 9. Finger segment is only indicated if the position is a finger code (0-10), and the finger segment is other than DST (fingerprints are assumed to be distal segment).
RolledPlain	Only used for exemplars. Values: ["Rolled" "Plain"]
InkLivescan	Only used for exemplars. Values: ["Ink" "Live"]
LatentProcessing	Only used for latents. Alphanumeric code from AN2011 Table 48 (for field 9.354 EFS latent processing method)
Substrate	Only used for latents. Alphanumeric code from AN2011 Table 51 (for field 9.355 EFS latent substrate)
Matrix	Only used for latents. Alphanumeric code from AN2011 Table 52 (for field 9.356 EFS latent matrix)
Comment	Free text for other descriptors of the file such as collection particulars or assessment of difficulty. Limited to 7-bit ASCII text. Tabs and carriage returns are not permitted. 99 character max.

6.2 Appendix B: Compliments and Enhancement Suggestions

This section is intended to provide both compliments received as well as suggestions for future enhancements based on tester feedback. Listed enhancements were found impractical to complete within the original period of performance or were out of scope. If further development is performed in the future, enhancement suggestions may be considered as areas to explore.

6.2.1 Compliments Received
- Cuyahoga County Regional Forensic Science Laboratory
  - *I love the training aspect. I usually use Photoshop to create an overlay of feature markup which can take an hour or more for eight examiners. ACEware would make that process so much easier.*
  - *Even if we didn't use it for casework, we could see ACEware being useful for storing case data for future review.*
  - *Marking minutiae is intuitive and easy.*
- Arizona Department of Public Safety Crime Laboratory
  - *If ACEware can serve as a central hub between multiple systems, it would solve a lot of problems with keeping data organized.*
- New York State Division of Criminal Justice Services
  - *Very impressive - incredible tool.*
  - *Having meetings with examiners to discuss difficult prints would be much easier with the overlay functionality.*
  - *Absolutely see value in ACEware, especially with the training functionality.*
  - *The reports functionality would be really useful in determining if searches we've submitted to the ULF contain sufficient markup.*
- Fairfax County Police Department
  - *Really like the concept of using datasets to create standard, reusable lesson plans for users (e.g. lesson on tonal reversal).*
  - *The information provided in the quality assurance reports would help identify examiners who may need more training or help us understand who isn't working as efficiently as they could.*
- FBI Laboratory
  - *The dataset functionality would be a great tool for compiling casework– from start to finish - especially for large cases.*

6.2.2 Enhancement Suggestions
- Allow individual examiners to assign verifications to other users.
- Allow verifications to be assigned in batches to better support large cases.
- Track multiple verifications made by different examiners to support double verifications (e.g., file is assigned to a second examiner after the first verifier has completed work).

- Allow verification results to be configured so individual organizations can define what results in a Critical Conflict/Conflict/Verified status.
- Maintain snapshots of quality markup over time to see progression of quality markup throughout the markup process.
- Allow reports to be generated based on selection of available data sources (e.g., Case ID, Case Prefix, Search result count, etc.) and output to a simple Excel file for record keeping.
- Display individual feature annotations made within Comparison Tool on printable reports
- Allow auto-minutiae functionality to be turned off for training purposes.
- Support custom relationship types for data set file association (e.g., same print lifted different ways and photographed from different angles)
- Display image quality map for individual users when comparing and combining markup.
- Allow users to be added through Windows Active Directory services.
- Enable case data to be pulled from other sources (LIMS).