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Introduction

On behalf of RTI International, the National Institute of Justice (NIJ) and the Forensic Technology Center of Excellence (FTCoE), we would like to present the proceedings from the 2018 Impression, Pattern and Trace Evidence Symposium (IPTES). The IPTES was held January 22–25, 2018, in Arlington, VA as the second joint symposium to promote collaboration, enhance knowledge transfer, and share best practices and policies for the impression, pattern, and trace evidence forensic science communities.

NIJ and FTCoE are committed to improving the practice of forensic science and strengthening its impact through support of research and development, rigorous technology evaluation and adoption, effective knowledge transfer and education, and comprehensive dissemination of best practices and guidelines to agencies dedicated to combating crime. The future of forensic sciences and its contribution to the public and criminal justice community is a motivating topic to gather expertise in a forum to discuss, learn, and share ideas. It's about becoming part of an essential and historic movement as the forensic sciences continue to advance. The IPTES was specifically designed to bring together practitioners and researchers to enhance information-sharing and promote collaboration among the impression, pattern, and trace evidence analysts, law enforcement, and legal communities.

The IPTES was designed to bring together practitioners and researchers to enhance information sharing and promote collaboration among impression, pattern, and trace evidence analysts, law enforcement, and legal communities. The planning and steering committees have worked with great effort to bring you 13 compelling workshops over Monday and Tuesday, followed by two full days of scientific sessions: two keynote addresses, three plenary sessions, two open panel discussions, 30 posters, and 48 oral presentations—totaling over 100 presenters.

This year our special keynotes included an address by Supervisory Special Agent Richard Marx of the FBI Evidence Response Team, sharing his expertise on "Forensic Science in a Mass Casualty Event (How Forensic Science Help Solved the Case)." Adam Benforado, Professor of Law at Drexel University and book author, spoke on the subject of his best seller "Unfair: The New Science of Criminal Injustice."

(continued)

Stakeholders of the criminal justice system continuously need venues such as this to share scientific developments that result from research, advances in forensic practice and operational management, and policy improvements. We are elated that the information sharing, networking, dialogue, and opportunities made this a memorable event for all attendees.

Respectfully,

Jeri D. Ropero-Miller, PhD, F-ABFT
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Gerry LaPorte, MSFS
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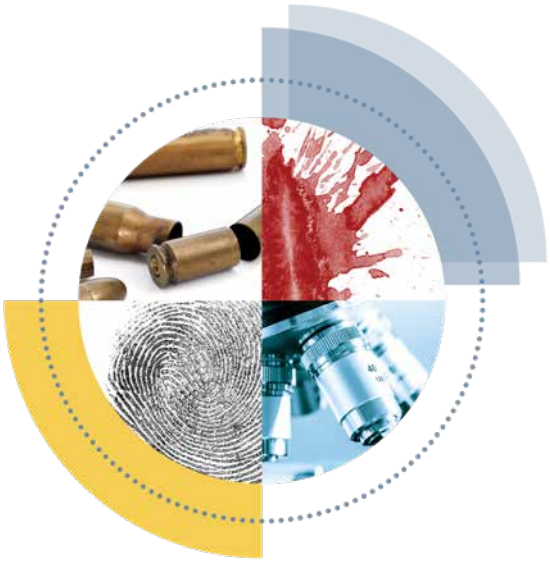
WORKSHOPS



Statistical Interpretation Software for Friction Ridge Skin Impressions (FRStat) Workshop

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Over the years, the forensic science community has faced increasing criticism by scientific and legal commentators, challenging the validity and reliability of many forensic examination methods that rely on subjective interpretations by forensic practitioners. Of particular concern, as noted in 2009 by the National Research Council (NRC) of the National Academies of Science (NAS) and the President's Council of Advisors on Science and Technology (PCAST) as recently as September 2016, is the lack of an empirically demonstrable basis to substantiate conclusions from pattern evidence. As a result, the ability for the judiciary to reasonably understand the reliability of the expert's testimony for the given case is limited. Consistent with several academic commentators, both the NRC and PCAST strongly encouraged the forensic science community to develop tools to evaluate and report the strength of forensic evidence using validated statistical methods. While these concerns apply to nearly every pattern evidence discipline, the forensic fingerprint discipline has received most of the attention because fingerprint analysis is one of the most widely used techniques in the criminal justice system. As a result, over the last several years, numerous methods and models have been proposed to provide a statistical estimate of the weight of fingerprint evidence; however, none have been widely accessible to the forensic community, thus prohibiting their ability to be further evaluated or implemented in routine casework. Consequently, forensic science laboratories throughout the United States have been unable to adequately address the concerns raised by the NRC and PCAST by demonstrating the reliability of fingerprint evidence for the case at hand.

Over the last few years, USACIL has been taking incremental steps toward the development, validation, and implementation of FRStat, a software that facilitates the evaluation and reporting of the statistical strength of fingerprint evidence. In March 2017, USACIL implemented FRStat in routine casework and began reporting the statistical strength of fingerprint evidence within the military criminal justice system. As of January 2018, FRStat was the only method known to be in operational use within the United States that provides the capability to ensure that the strength of fingerprint evidence is evaluated against an empirically grounded basis.

Through a combination of lectures, group discussions, and practical exercises, this workshop provided participants with the appropriate knowledge, skills, and abilities to establish a statistical foundation to latent print examinations using FRStat software to ensure that examinations are conducted and conclusions articulated in a more scientifically defensible manner.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the US Department of the Army or US Department of Defense.

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Implementation of 3D Technology, Analysis, and Statistics for Firearm and Toolmark Examinations

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This full-day workshop provided foundational knowledge and real-world applications of emerging research, tools, and automated technologies for firearm and toolmark (FA/TM) analysis. The workshop provided an overview of the direction and methodologies currently employed in FA/TM research as well as future roles in which these technologies can be used. A case study was presented on how the FBI Laboratory Firearms/Toolmarks Unit (FTU) has been evaluating, validating, and incorporating 3D technologies into casework and mapping out the challenges that laboratories could face with implementation. Attendees also had an opportunity to participate in several Collaborative Testing Services (CTS) tests using virtual comparison microscopy to learn about its utility in everyday casework.

The goal of this workshop was to provide participants with foundational knowledge of emerging tools and technologies related to FA/TM comparisons. Training included the theory underlying different styles of 3D microscopes, the acquisition of quality traceable data, processing methods for raw data, quantitative comparison algorithms, statistical frameworks for FA/TM, and virtual microscopy (VM). Participants walked away from this training armed with operational knowledge for future implementation of advanced 3D technologies in their laboratories.

This workshop presented a potential framework for the future use of automated technologies to supplement an FA/TM examiner's comparisons. The technologies and algorithms presented comprised a pathway to directly quantify an objective identification metric with associated statistical error rates.

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Intra- and Inter-variability of Footwear Test Impressions: An Interactive Workshop

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This workshop was based on The Northwest Association of Forensic Scientists' (NWAFS) Special Research Topics. However, instead of a workshop with one presenter and many students, this workshop was a collaborative effort involving all the participants, with "mentors" guiding the research. This workshop was intended to conduct baseline research that generated data to be formally published at a later date.

There is currently no known published research that addresses the differences in examiners' physical attributes (e.g., foot size, weight, and gait) and how they might affect test impressions.

This workshop was designed to answer basic questions such as: How much size variation is there when one person makes a test impression? How much size variation is there between individuals making test impressions with the same shoe? Are different examiners able to repetitively capture/replicate RACs in their known test impressions?

This workshop involved using three different sets of shoes. Two of the sets contained a total of three of the same make/model shoes in sizes 9, 11, and 13. One of these two sets had a continuous outsole design, and the other had a design with a separate heel and toe. The third set consisted of one size 15 shoe. Marks (RACs) were made in similar locations on the outsole of each shoe. Additionally, each participant had their feet measured using a Brannock Device.

The participants each made three test impressions with each shoe using an Identicator® Inkless Shoe Print Kit (The Safariland Group). The test impressions were then scanned at 600 ppi. Each student evaluated the test impressions they made and annotated how many known RACs were captured on their test impressions. A predetermined and consistent set of marks on each outsole were measured using Photoshop (or a similar program). The students then recorded their measurements of predetermined RAC locations.

Once all the workshop participants had completed their assessments and measurements, the class was opened to all other symposium attendees. These attendees contributed to the data pool by making exemplars with the aid of the workshop participants. Attendees also joined the class to observe and discuss.

Each person had a range, mean, and standard deviation calculated for each shoe. The resulting values were compared to the group's ranges, means, and standard deviations for each shoe size using analysis of variance (ANOVA). Spreadsheets with formulae were developed prior to the workshop. Fully analyzed data were available to the workshop attendees at the conclusion of the workshop. Further work will be required from all participants prior to publishing the data.

The significance of these findings as they relate to casework was not be critically evaluated. The data collected from this workshop may offer information on what is, or is not, being recorded when one takes a test impression. However, the data collected and statistical analysis conducted will facilitate further study. This workshop was limited to six participants plus the two mentors.

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Probabilities and Likelihood Ratios in Pattern Evidence Evaluation

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Probabilities and likelihood ratios (LRs) provide an important framework for evaluating evidence. Many practitioners are interested in better understanding the relevance of the LR framework to their professional practice. This workshop introduced the LR framework in the context of assessing pattern evidence using examples from latent prints, footwear impressions, and toolmark impressions. We discussed how the LR framework relates to common current practices and how computer-aided, quantitative comparisons can benefit evidence evaluation. The workshop was designed to give participants a sound conceptual understanding of probabilities, LRs, and their potential strengths and limitations.

Scope:

a. Starting from first principles, explain to practitioners what probability is, what LRs are, and why these are useful ideas when thinking about communicating the evidence to triers of fact.
b. Use examples from pattern evidence disciplines to illustrate these concepts.
c. Use simple interactive exercises to enable participants to experience the process involved in arriving at probabilities and LRs.
d. Explain the need for extensive exploration of the basis upon which judgments of probabilities and LRs are made.

Objectives: Our objective was to address these points without the using technical terminology or complicated mathematical equations and without sacrificing the key underlying concepts. We believe that a high level of mathematical sophistication is not necessary to understand the fundamental ideas.

We used many examples based on pattern evidence disciplines to communicate the essential ideas. We also incorporated hands-on exercises in which the participants went through the steps involved in assessing probabilities and LRs. This enabled them to identify areas in which personal judgements were made based on their training and experience and/or available empirical data.

Upon completion, the participants had a good grasp of the fundamental concepts of probability and LRs.

Brief Narrative Introduction: The workshop comprised two modules. The first module (morning session) was a logically complete unit by itself so that participants who were able to attend only the half-day session can still benefit from the information presented. The second module (afternoon session) provided an opportunity to include extended discussions, Q&A, and additional hands-on activities that provided further insights.

Morning session

- We presented an assortment of case-like pattern comparisons to introduce the fundamental questions of the LR framework (similarity and typicality): Could the questioned pattern have originated from the same source as the control

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pattern? Could it have originated from a different source? What information influences our responses to these questions?

- A brief illustration using coin flipping and sampling jelly beans from a jar introduced concepts of probability and LRs.
- We then conducted a hands-on exercise to examine and categorize pairs of paper samples and make a conclusion (i.e., same source/identification, different source/exclusion, or inconclusive). Using ground truth and the reported conclusions, we assessed error rates and LRs for each conclusion level.
- We revisited the collection of comparisons to further refine the ordering in terms of perceived similarity and constructed a corresponding receiver operating characteristic (ROC) chart.
- We used the ROC chart to translate the perceived similarity in "case" assessments to corresponding score-based LRs.
- We discussed the importance of identifying a case-specific collection of reference comparisons when evaluating method performance.
- We also discussed the influence of within- and between-examiner variability and the size of the reference collection used on assessments of comparison method performance.

Afternoon session

- Hands-on activity: Participants worked with fingerprint pairs (simulated and realistic) and made a conclusion (i.e., identification, exclusion, or inconclusive). Using the results, they constructed an ROC chart. They were also shown the results from a computer fingerprint-matching algorithm and the associated ROC chart. The group discussed the information relayed by these charts. The activity also led to error-rate discussions and associated issues.
- Hands-on activity: Participants worked with footwear impression pairs (simulated and realistic) and followed steps similar to those used in the case of fingerprints.
- Computer-assisted quantification of similarities between latent and exemplar pairs was discussed, and the use of ROC charts for discriminating between better algorithms and poor algorithms was illustrated.
- Score-based LRs were introduced. Mated and nonmated score distributions were described. The strengths and limitations of statistical modeling of these distributions were discussed and illustrated.
- Participants were given ample time to ask questions on any of the concepts discussed in the workshop, and the Q&A session was followed by a group discussion and instructors' opinions.
- Key concepts from the workshop were revisited in summary form.

Methods/approach: We illustrated the underlying concepts using pattern evidence discipline examples and hands-on exercises, as outlined above.

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Results and findings: Our own past experience with teaching workshops has demonstrated that practitioners can appreciate and understand probability and LRs without needing any particular prerequisite other than logical thinking. This workshop was built on this premise.

Conclusions: The more familiar a practitioner is with the concepts of probability and LRs, the more comfortable they can be when communicating forensic evidence to triers of fact during courtroom testimony or when writing forensic examination reports.

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Forensic Wood Identification

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Wood examination is one of the ever-shrinking specialty areas of trace evidence that needs to be supported. Training in such areas is difficult for individual laboratories to provide. The object of this workshop was to combine an introductory-type workshop for inexperienced examiners with a platform for examiners who infrequently perform examinations and would like to expand their experience. The hands-on approach was crucial to ensure that the participants understand both the sample preparation techniques and morphological characteristics needed for success in wood characterization. Examining whole wood blocks and forensic-sized samples were included in the laboratory exercises. Examiners with no experience could begin with lectures on wood structure and sample preparation techniques. Examiners with experience could begin the laboratory exercises immediately, working in pairs.

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Applied Polarized Light Microscopy for Trace Evidence Examiners

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This workshop introduced participants to the theory and application of polarized light microscopy (PLM). This technique is extremely versatile and can provide valuable data for the identification, characterization, and comparison of a wide variety of trace evidence materials. Lecture presentations were supplemented with hands-on microscopy exercises designed to reinforce the material. Topics covered included lectures and/or exercises related to image formation, proper microscope set-up, refractive index measurement, basic optical crystallography, retardation and birefringence, extinction characteristics, and compensators. The afternoon of the second day provided participants with an opportunity to practice the covered techniques.

Scope: This 2-day workshop was designed for trace evidence examiners who either lack formal training in PLM or whose training in this area was not recent. This was a hands-on workshop that included lecture presentations, instructor demonstrations projected from a microscope, and participant exercises using polarized light microscopes and prepared samples. The workshop introduced participants to fundamental PLM concepts, including the basic optics involved in image formation in a compound light microscope, refractive index, isotropy, anisotropy, retardation, birefringence, extinction characteristics, compensators, and basic optical crystallography. The theory behind these concepts was paired with practical exercises designed to teach participants to make appropriate measurements/observations of their samples and understand the significance of their observations. Participants had opportunities to apply what they learned to real-world samples that are relevant to multiple trace evidence disciplines.

Narrative: This workshop introduced participants to the theory and application of PLM. This technique is extremely versatile and can provide valuable data for the identification, characterization, and comparison of a wide variety of trace evidence materials. It is essential equipment for virtually all hair and fiber analysts but has broad applications beyond this discipline in areas where it is much less widely used. For example, PLM can be used to identify and characterize pigments and fillers in paint, polymers, tape, and adhesives. It is a critical tool for the examination of soil and other geological evidence and is valuable for the identification of explosive materials and residues. PLM can also assist in the identification of glass fragments and is an essential piece of equipment for the identification of general unknowns.

Despite its utility in analytical chemistry, PLM instruction is rarely included in university chemistry curricula. This workshop provided an introduction to this topic for trace evidence examiners who did not obtain PLM training during their formal education and a refresher for trained practitioners who have not used this instrument on a regular basis.

The two presenters have over 30 years of combined experience in microscopy instruction, and they both routinely have applied PLM in their casework and research activities. Based on this experience, the presenters believe that hands-on activities are essential to learning this technique. During this workshop, the lecture presentations were supplemented with live demonstrations through

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an instructor microscope and hands-on microscopy exercises designed to reinforce the material. These lectures, demonstrations, and exercises were designed to teach participants about image formation in a compound light microscope, proper microscope set-up (Kohler Illumination), refractive index measurement, basic optical crystallography, isotropy and anisotropy, retardation and birefringence, extinction characteristics, and the use of compensators. On the afternoon of the second day, participants practiced the covered techniques. Participants were encouraged to bring in materials similar to those encountered in casework so that they could apply the workshop training to real-world samples relevant to their work.

The goal of the workshop was to provide a foundation of basic PLM theory and application that participants can use as a starting point in their professional microscopy training. This experience enabled participants to attend future workshops or professional training courses with basic PLM training as a pre-requisite.

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3D Footwear and Tire Tread Impression Capture

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This workshop provided an overview of state-of-the-art nondestructive optical 3D scanning technologies and allowed participants to interact with and evaluate a prototype portable structured light 3D imaging system for capturing shoe and tire impressions. The goal of this NIJ-funded project is to develop a fully automated portable system with an easy-to-use-graphical user interface (GUI) that can capture shoe or tire impressions in substrates such as snow or soil, which are typically challenging to analyze using optical 3D scanning technologies. Ultimately, we hope that this more affordable and easy-to-use 3D scanning system will be commercially available to the forensic community to improve both the collection and analysis of 3D impression evidence. After the hands-on portion, practitioners also had an opportunity to discuss how 3D images could be incorporated into laboratory comparisons and case workflow.

The entire hardware system includes a digital complementary metal–oxide–semiconductor (CMOS) camera, a digital-light-processing projector, and a laptop computer. The camera and projector are precisely synchronized to allow a sequence of defocused binary structured patterns to be precisely captured by the camera. The captured images are processed to create a 3D surface map at camera pixel spatial resolution and, simultaneously, a color photograph (or texture) that is 100 percent aligned with the 3D point. The image acquisition takes a fraction of a second, and the automatic 3D reconstruction takes a few seconds. 3D data can be immediately visualized on the screen for quality examination or saved to a media in standard 3D mesh formats (e.g., OBJ, STL, or PLY).

The GUI includes the camera control module, visualization module, and data-handling module. The entire GUI was developed with Qt, C++, OpengGL, and OpengCV, with special emphasis on making the GUI intuitive and easy to use. The camera control module allows a user to manually/automatically adjust exposure of the camera and then click a button for 3D image acquisition. The visualization module enables the user to examine the quality of the data in both 2D and 3D. This module allows 3D data manipulation, such as zoom-in and zoom-out, rotation, and translation, and the selection of different visualization modes, such as shaded, textured, or mesh rendering. The data-handling module offers data reading/writing and filtering, if the user chooses it.

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Fracture Examinations Workshop

Scope: Many objects can be broken, torn, or cut apart at crime scenes and associated with objects found at other investigative locations. The workshop covered a range of topics from how things or objects are generated in nature or manufactured to how objects are naturally or unnaturally broken, torn, cut, or separated. The processes of human judgment and decision-making was be discussed. Then, the process of examining things was addressed, followed by many practical exercises using known ground truth objects and pieces of objects to determine whether the separated pieces had ever been connected to each other.

Narrative: After an introductory lecture and discussions during the workshop, the participants and instructor broke, tore, separated, or cut a variety of objects and then reassembled the pieces of those objects. Then, the participants examined pieces of objects that the other participants had previously broken, torn, separated, or cut. Subsequently, they examined pieces of objects that the instructor had previously broken, torn, separated, or cut. The comparative scientist participants studied the repeatable and unique features of broken, torn, separated, or cut objects often found at crime scenes to ascertain whether they had once been connected to and part of each other. After analyses, comparisons, and evaluations, the participants developed a better understanding of how to make a judgment regarding whether items had ever formed a continuous object based on the quality and quantity, levels of clarity, and levels of measurements of the repeatable and unique features of the pieces.

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Expert Assisting Computerized System for Evaluating the Degree of Certainty in 2D Shoeprints

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Both the 2009 National Research Council (NRC) report, *Strengthening Forensic Science in the United States: A Path Forward*, and the recent President's Council of Advisors on Science and Technology (PCAST) report, *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*, urged the forensic science community to put "more science into the forensic science." This is a very challenging task, and despite the significant effort consistently directed toward fulfilling this objective, this goal has not been fully accomplished.

A practical method of conducting pattern comparison is clearly demonstrated by the shoeprint examination process. Today, shoeprints found at crime scenes are compared manually against suspect shoes. The first step is to determine whether the class characteristics, such as the sole pattern, size, and wear, match. Matching these features narrows down the potential population of shoes that could have left the shoeprint, but their discriminative value is limited. Once a match is achieved in all class characteristics, the shoeprint comparison examiner searches for accidental characteristics that appear both on the sole of the shoe and on the shoeprint from the crime scene. Randomly acquired characteristics (RACs) are features on a shoe outsole resulting from random events of the removal or addition of material to the outsole. These include but are not limited to cuts, scratches, tears, holes, stone holds, abrasions, and the acquisition of debris. The location, orientation, and shape of these characteristics must match to support the connection between the shoe and the shoeprint. If such RACs are identified, the examiner evaluates their rarity based on his knowledge and experience and the level of confidence derived from the combination of all the accidentals found on the shoeprint. This process depends heavily on the expertise and subjective decisions of the examiner. An automated method for calculating the rarity of RACs would be more objective and, thus, increase the reliability of the results.

An extensive research project conducted during the last decade (sponsored partially by the National Institute of Justice [NIJ]) made a major step in this direction: a computer algorithm that will enable the shoeprint expert to quantitatively estimate the evidential value of RACs is being developed.

Test impressions, which are controlled prints made with the examined shoe, were collected for this research. The test impressions were created according to international standards. The outcome is a good representation of the shoe. A database of over 13,000 RACs from nearly 400 shoe soles was collected semi-automatically. The location, orientation, and contour of each RAC on each impression were determined. An algorithm for evaluating the rarity of RACs was developed and can be used to assist in reaching an expert opinion rather than relying on the examiner's memory and presenting the reasoning in court.

This software focused on RACs only and not on the patterns of soles or other class characteristics. The rationale behind this decision was that the shoe industry changes its shoe sole patterns frequently, and therefore, a database of

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shoe sole patterns would have a short lifespan. In contrast, the materials used to manufacture shoe soles are not altered frequently, and the tearing behavior of all shoe soles is similar. Thus, such a database will be useful for an extended period of time.

The methodological concept presented during the workshop represents a large step toward transforming the entire area of pattern comparison to an agreed-upon, scientifically based field. It may also lead to the establishment of large databases and algorithms to calculate the chance to find other features, similar (under restrictions) to those examined for the various comparison fields.

In this hands-on workshop, participants learned how to use a program for the computerized detection of the borders of RAC contours and a beta version of a RAC match-evaluating software, including demonstrations. The rarity of accidental characteristics on an example sole (as seen on the test impression) was also evaluated. The meaning of each step was discussed, as were current limitations and future improvements.

All of the participants received a DVD with the dataset and applications.

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No More Either Or: Working Together to Solve Compatibility Issues Between Impression Enhancement and DNA Analysis

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Impression evidence, both blood and nonblood, is a common component at many crime scenes. Current fluorogenic enhancement methods for impression evidence are problematic for DNA preservation and are often impractical for crime scene use. This may lead to an either/or decision made during evidence collection based on whether to enhance the impression and potentially damage the DNA evidence or gather the DNA evidence, which may destroy impression evidence.

Zar-Pro™ Fluorescent Blood Lifting Strips have been successful in lifting, enhancing, and preserving bloody impression evidence, providing a highly sensitive method for processing and fluorogenically enhancing bloody impression evidence that can be preserved and utilized over long time intervals. However, the viability of subsequent DNA analyses has not been established.

This project proposed an integrated two-phase approach, in a collaboration between impression specialists and DNA analysts, to test the viability of DNA in evidence processed with Zar-Pro™ lifters and to develop and optimize a DNA extraction protocol suitable for use with this technology. During the initial phase of the project, over 1,200 impressions were laid in five biological fluids on a series of seven substrates that range from nonporous to semi-porous to porous. To determine the viability of the DNA over time when fixed to the Zar-Pro™ lifters, trials were established to test 3-month, 6-month, and 12-month intervals.

The preliminary results are encouraging and show that DNA is preserved and can be retrieved from impression evidence lifted and enhanced using Zar-Pro™ lifters. The findings support the ideal situation: collaborators working together to overcome challenges in evidence collection and analysis. The goals of this project include the development of simple, time- and cost-effective, nontoxic methods that are safe for use at crimes scenes and provide opportunities for subsequent DNA recovery in the laboratory. Simplifying collection and preservation while expanding the utility of impression enhancement methods to include DNA analysis has the potential to transform how technicians approach crime scene evidence.

We provided a presentation of this research and then a workshop demonstrating the Zar-Pro™ Fluorescent Blood Lifting Strips and allowed participants to use the technology themselves.

Materials for this workshop were donated by Tri-Tech forensics.

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Analyzing Interactions of Latent Prints with Blood

Generally, bloody fingerprints are understood to occur when blood is present on the finger at the time of deposition. In the past several years, questions have been asked in courtrooms regarding whether an apparent bloody fingerprint may actually have been caused by other mechanisms, such as blood interacting with a latent print already on the surface or a clean finger making contact with a surface already contaminated with blood. Research into these propositions has shown that they could indeed be possibilities. As a result, the probative value of an apparent bloody fingerprint may be called into question. Because of the correlation between this type of evidence and violent crimes, better understanding of this topic is needed to alleviate doubt in relevant cases. Research has also shown that the various mechanisms may be distinguishable based on the characteristics and details visible within an impression, particularly if images of the questioned impression both before and after processing with any chemical reagents are available. Therefore, careful analysis of apparent bloody fingerprints is essential to provide clarity in each case. Although there is no method to prove which mechanism actually produced an apparent bloody fingerprint, a thorough analysis with attention to the specific details that have been shown to be useful in distinguishing one theory from another is vital if the evidence is disputed.

The goal of the workshop was to provide the participants with the knowledge and skills to appropriately analyze apparent bloody impressions, focusing on details that may not necessarily aid in the identification or exclusion of a source but that are important to document because of the challenges that could arise given recent defense inquiries. Upon completion of the workshop, participants had learned to provide a complete record of their observations for a court to consider in the event that such a record is needed.

The proposed workshop introduced participants to this topic and the research that has been conducted in recent years. The primary focus was on a paper published in 2013 by the workshop presenters, but relevant research by others will also be included. Participants were instructed on what characteristics/details to analyze in apparent bloody impressions and how to document them accurately. A demonstration exercise was completed as a group prior to independent work. Working with images only, each participant completed ten practical exercises within an hour. The exercises presented a variety of images, representing each of the three discussed mechanisms and including both processed and unprocessed impressions. Next, the group reviewed each exercise together to discuss what details were present and documented in each image. The mechanism that produced each image was revealed, and the group had the opportunity to compare and contrast these results with the characteristics observed. Finally, real case studies were presented to demonstrate bringing practice into application.

Reference

Praska, N., & Langenburg, G. (2013). Reactions of latent prints exposed to blood. *Forensic Science International, 224*(1–3), 51–58.

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Foundations of the Interpretation of Pattern and Trace Evidence (Source and Activity Levels)

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Forensic scientists involved in trace, pattern, and impression evidence are typically mandated to (1) determine the nature of unknown substances, (2) conduct comparative examinations to offer conclusions on the source of recovered material or impressions (defined as "source" level inference), or (3) provide information on the relevance and usefulness of the recovered material or impressions in the context of a case (defined as "activity" level inference).

Addressing these questions requires the analyst to "interpret" the (analytical or observational) results obtained from the examination of the evidence. In other words, it requires the use of a framework to transform the data resulting from the examination of the trace and reference material into information that can be reported to any party in the legal system.

This inferential framework must be logical, coherent, and scientifically supported. Furthermore, forensic scientists need to be able to explain, justify, and present their thought process to their audience. When interpreting evidence, the expert needs to consider the questions relevant to the case, avoid major interpretive fallacies, and, overall, consider uncertainties related to the generation, recognition, collection, examination, and evaluation of the evidence. Only then will the analyst combine all these pieces of information to form a conclusion.

The scope of this workshop was to introduce a decision-theoretic model that formalizes human decision-making and use it to explore the interplay among the different types of questions, data, and sources of bias commonly encountered by forensic scientists and the different conclusion schemes that are used in the different sub-fields.

In this workshop, both trace and pattern/impression evidence was regarded beyond the traditional view of source determination. We considered that a piece of forensic evidence is the result of an activity or a set of plausible activities. A decision-theoretic model was used throughout the workshop to highlight some key aspects of inference in forensic science to answer questions at the "source" and "activity" levels using case contextual information. The proper sequence of revealing the case information—commonly known as "sequential unmasking"—was also be explored.

By applying the model during case studies and exercises, the participants explored how to formulate relevant questions that may be of interest to the legal system. For example: at what point of the examination process should these questions be formulated? What type of information (e.g., location, transfer, persistence, recovery, detection, quantity, or match probability) is necessary to address these questions? These exercises also enabled the participants to appreciate how the different conclusion schemes commonly used by forensic scientists are related to one another, identify their capabilities and their pitfalls and limitations, and realize that the lack of availability of a certain type of information may limit their choice when deciding which type of conclusion to

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report. Finally, the model was used to identify the different steps in the decision-making process where errors may occur or where an examiner's thought process may be subject to bias. Recognizing these sources of error and potential bias enabled the participants to devise strategies, such as sequential unmasking, and importantly, when to implement these strategies. The overarching goal of the workshop was to institute an approach, codified in a program, to limit the occurrence of erroneous conclusions.

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Chemometrics Without Equations for Forensic Scientists

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Chemometrics is the use of mathematics, chemistry, and logic to obtain information from chemical systems. Recently, it has become increasingly important for criminalists to learn the principles of chemometrics so that that they can understand current forensic science literature and potentially utilize these statistical methods in casework. This workshop was created so that those not fluent in matrix algebra can take advantage of the powerful tool of chemometrics.

There are three potential uses of chemometric analysis: exploratory analysis, regression analysis, and classification. Exploratory analyses, such as PCA, seek to discover possible outliers and reveal whether there are patterns or trends in the data. Regression analysis is used to predict related properties with the goal of developing a model that correlates the information in the set of known measurements to the desired property. Partial least squares (PLS) and principle component regression (PCR) are examples of chemometric algorithms for performing regression. Chemometric classification is the assignment of samples to predefined categories and predicting that an unknown sample belongs to one of several distinct groups. Canonical variate analysis (CVA) and PLS discriminant analysis (PLS-DA) are examples of chemometric classification techniques.

This introductory workshop concentrated on two areas of chemometrics: (1) exploratory data analysis and pattern recognition and (2) regression. Participants learned to apply techniques such as PCA, SIMCA, PCR, and PLS safely. The most commonly used methods of outlier detection and data pretreatment were also illustrated. Understanding the chemometric process without having to learn matrix algebra was emphasized.

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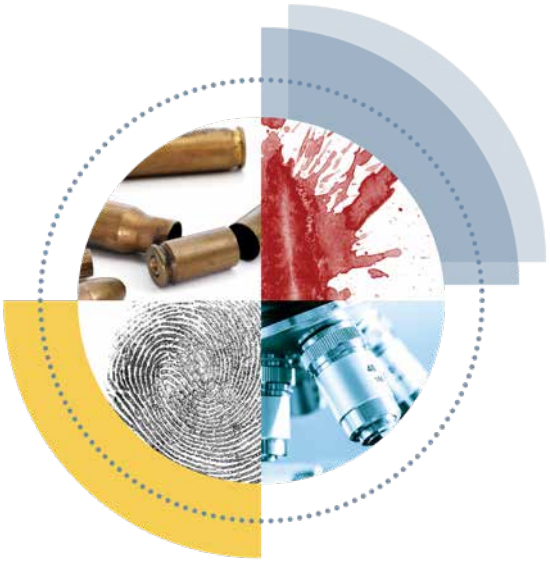
GENERAL SESSIONS



Reality Check—What Is Expected from Expert Witnesses

Steven Lund, PhD

National Institute of Standards and Technology

Forensic practitioners often cite training and experience as the basis of expertise when offering an opinion or conclusion in report writing or testimony. Indeed, for any discipline, the observations made by a field of experts inform many aspects of evidence evaluation, such as what results a given evaluation method has produced under different scenarios, what evaluation methods have been effective in discriminating between possible scenarios, and what factors have affected the performance of a given evaluation process. Experts are frequently expected to reach beyond what could be supported by data alone (even with a large database) to provide the meaning of their findings for a particular case. Such inferences require assumptions that may fall outside the realm of anyone's expertise and raise the need for nontrivial uncertainty assessments.

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Challenges Faced by Experts When Communicating Forensic Evidence to Triers of Fact: A Statistician's View

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During a criminal trial, triers of fact receive evidential information from experts. They are expected to process this information and arrive at a conclusion regarding the "guilt" or "innocence" of the defendant being tried. In an ideal system, there would be no wrongful convictions and no erroneous acquittals. In practice, errors do occur, and we seek a system that minimizes such errors. The challenge is that, in actual cases, the system rarely receives feedback as to whether the decision arrived at in any particular case was correct or incorrect. The information presented by experts to the triers of fact, and the manner in which this information is presented, are important components of the judicial system that could have a significant effect on the correctness of court decisions. In this presentation, we outlined some common modes of information transfer from experts to triers of fact and identify advantages and disadvantages of some of these modes.

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The Use of Similarity Measures (Scores) to Quantify the Weight of Forensic Evidence

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Legal and scientific scholars are promoting the use of the Bayesian framework to describe the interaction of the information provided by a piece of forensic evidence with other pieces of information (e.g., background information, other case information, other forensic evidence). By extension, these scholars propose to quantify and report the weight of a given piece of evidence using a Bayes factor (also called "likelihood ratio"). Assigning Bayes factors requires one to define and measure features from objects of forensic interest (e.g., minutiae location, type and direction on a friction ridge impression), represent these features in some mathematically compatible manner (e.g., transmittance as a function of time for the spectrophotometric analysis of a fiber), and model their probability distributions.

Apart from trivial situations, such as the refractive index of glass shards or the designation of the alleles in a single forensic DNA profile, forensic evidence can only be represented using high-dimension heterogeneous vectors of random variables, whose probability distributions cannot be modelled. To address this issue, some have proposed to summarize forensic evidence using similarity measures (such as the Automated Fingerprint Identification System (AFIS) or Integrated Ballistic Identification System (IBIS) scores) between pairs of objects, and to quantify the weight of the evidence represented by these similarity measures. Unfortunately, the use of similarity measures to represent forensic evidence introduces significant biases in the resulting weight of a piece of evidence.

The purpose of this presentation was to review the benefits and expose some of the limitations of "score-based Bayes factors." During this presentation, we described several possible ways to construct "score-based Bayes factors" and study their convergence to the "true value" of the Bayes factor using examples where that value exists. Our results show that "score-based Bayes factors" may over- or undervalue the weight of the evidence in unpredictable ways. Furthermore, our results show that the advocated use of so-called "calibration methods" does not improve the lack of reliability of "score-based" methods. Finally, our results show that, except in one situation, "score-based Bayes factors" are not coherent with respect to the fundamental axioms of probability. Our results led us to conclude that efforts to quantify the weight of evidence in a more transparent manner, when based on similarity scores, may result in the same types of unreliability issues with respect to forensic conclusions, than the ones that are of great concern today. At the end of this presentation, we discussed research avenues that address the issues of dimensionality and heterogeneity, while being statistically rigorous and coherent.

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Statistical Analysis in Forensic Science Evidential Value of Multivariate Data

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In this presentation, recent advances in likelihood ratio (LR) computation for multivariate trace evidence were discussed. Several different techniques were identified as important to explain the latest improvements in the performance of LR models for forensically realistic datasets. Some examples were given, mainly for laser ablation inductively coupled plasma mass spectrometric glass analysis. Rigorous and appropriate empirical validation before their use in casework was highlighted as critical for any LR model. Finally, different avenues to be explored in future research were proposed.

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The Anatomy of Forensic Identification Decisions: Rethinking Current Reporting Practice in a Decision-Theoretic Perspective

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Over the past few years, forensic identification practice has seen a semantic shift in the labeling of expert conclusions. Increasingly, the notions of identification and individualization are referred to as decisions. At the same time, substantial progress has been made in developing balanced and transparent approaches for quantifying the probative value of the results of comparative forensic examinations (e.g., using likelihood ratios). This field of practice and research is now more generally known as "forensic interpretation." Further, it has become clear that the proper role of scientists in forensic interpretation is to focus only on the findings and their value and to avoid expressing direct opinions as to the (probable) truth of propositions. However, researchers and practitioners who adhere to traditional reporting formats such as "identification" and "exclusion" are still critical of such approaches. In my talk, I critically examined this traditional position from a decision-theoretic viewpoint.

First, I presented the standard ways in which the notion of decision is understood and used in a variety of fields, including statistics and the law. This review will also include the empirical perspective emphasized by the President's Council of Advisors on Science and Technology (PCAST) in its recent review of selected branches of forensic science.

Second, I introduced elements of decision theory and illustrated them in the context of forensic inference of source. This formal analysis aimed to unravel the logical structure—that is, the anatomy—of what is at stake for any decision-maker attempting to reach forensic inference of source conclusions. In particular, I argued that the understanding and justification of forensic identification as a decision requires assumptions to be made about key issues that lie beyond the forensic examiner's area of competence. A typical example for such an assumption is the assessment of the relative undesirability of erroneous decisions. This decision-theoretic perspective calls traditional reporting policies and formats into question, especially categorical conclusions of common source.

I further argued that the understanding of the broader process of forensic inference of source as a decision problem does not conflict with reporting practices restricted to the value of the findings only but can accommodate it neatly as a defensible reporting format.

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Statistical Interpretation and Reporting of Fingerprint Evidence at the US Army Criminal Investigation Laboratory

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The results of forensic fingerprint examinations are traditionally based on the visual comparison and subjective opinions of forensic examiners and reported as categorical statements of inclusion or exclusion of a particular individual as the source of a latent print. In 2009, the National Research Council (NRC) encouraged the forensic science community to develop tools to evaluate and report the strength of forensic evidence using validated statistical methods rather than rely solely on the subjective opinion of forensic examiners. The recommendations of the NRC are consistent with those of the President's Council of Advisors on Science and Technology (PCAST) in 2016 and the American Academy for the Advancement of Science (AAAS) in 2017. The primary concern of the NRC, PCAST, and AAAS is the legal field's inability to assess the reliability of fingerprint comparison results for a given case at hand without validated statistical data concerning the strength of the findings, thus bringing into question the scientific validity of fingerprint evidence and its admissibility in criminal courts.

Over the last few years, the United States Army Criminal Investigation Laboratory (USACIL) has been taking incremental steps forward to facilitate the transition from solely subjective, experience-based practices to integrating more robust, scientifically demonstrable, and data-driven practices for latent print examination. As part of this effort, the USACIL has developed, validated, and implemented a method that facilitates the evaluation and reporting of the statistical strength of fingerprint evidence. In March 2017, the USACIL began reporting the statistical strength of fingerprint evidence within the military criminal justice system and is currently navigating a way forward for the broader forensic fingerprint discipline toward stronger scientific foundations and improved practices. This presentation provided a general explanation of the statistical methods employed; discussed policies and procedures governing their use in casework; and discussed how other federal, state, and local forensic service providers can work toward implementing similar reforms within their laboratories.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the US Department of the Army or US Department of Defense.

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LR Testimony Cross-Examined

Likelihood ratios (LRs) provide an important framework for evaluating evidence, but there are potential issues with their envisioned casework implementation. A primary concern is the adequate portrayal of the extent to which reported LR values depend on personal modeling choices. We presented hypothetical cross-examinations of an expert offering LR testimony based on (1) a single model and corresponding validation effort and (2) an extensive collection of plausible models designed to inform uncertainty. This effort emphasized the importance of candidly illuminating relationships among interpretation, data, and assumptions.

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Scope:

a. Explained to practitioners what the strengths are of the LR paradigm when thinking about communicating evidence to triers of fact.
b. Explained what role data, assumptions, and models play when attempting to summarize the evidence in terms of a single number LR to be used as weight of evidence.
c. Explained the personal choices that are often made when developing models for LR.
d. Explained the need for extensive exploration of alternative assumptions and models and their impact on LR calculations for the testimony to be considered science-based and to withstand cross-examination.

Objectives: Our objective is to address the points mentioned above using an easily understandable example series of questions an attorney might ask an expert witness regarding the process involved in the witness's assessment of LR. The ideas can be presented in a way that is accessible to a general audience and that does not appeal to technical details. We used two scenarios—(1) a scenario where the expert relied on a single model with the claim that it has been validated and (2) a scenario where the expert conducted an extensive analysis of many plausible models to provide information regarding uncertainties associated with the offered LR—to demonstrate the effectiveness (or lack thereof) of each method to give a fair portrayal of uncertainties and to be able to withstand informed cross-examination.

Brief narrative introduction: In response to calls from the broader scientific community and concerns of the general public, experts in many disciplines of forensic science have increasingly sought to develop and use quantitative methods to convey the meaning of evidence to others, such as an attorney or members of a jury. Support is growing, especially in Europe, for a recommendation that forensic experts communicate their findings using an LR. If an LR is reported, however, experts should also provide information to enable triers of fact to assess its fitness for the intended purpose. A primary concern should be the extent to which a reported LR value depends on personal choices made during its assessment. Even career statisticians cannot objectively identify one model as authoritatively appropriate for translating data into probabilities, nor can they state what modeling assumptions one should accept. Rather, they

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may suggest criteria for assessing whether a given model is reasonable. Our described framework explores the range of LR values attainable by models that satisfy stated criteria for reasonableness. The exploration of several such ranges, each corresponding to different criteria, provides the opportunity to better understand the relationships among interpretation, data, and assumptions.

Methods/approach: We illustrated the underlying concepts using two hypothetical cross-examination scenarios involving an expert offering LR testimony in court. Scenario 1 assumed that the expert bases his or her interpretation on a single model with associated validation efforts. Scenario 2 was based on an expert who has conducted a thorough investigation of many plausible models and was better able to convey the range of LR results that might be considered plausible. The presentation was accessible to a general audience.

Results and findings: Our own theoretical investigations have demonstrated that, depending on the amount of empirical information available, the range of LR values one might consider reasonable may be so wide that the validity of a single number offered to triers of fact may be unjustified or it may be unfit for purpose.

Conclusions: Unless the expert offering LR testimony has conducted extensive uncertainty analysis and provides this information during testimony (or in reports), triers of fact will be unable to assess the weight of the provided evidence in an informed manner.

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Factors Which Influence Juror's Interpretation of the Value of Forensic Science Testimony

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Husson University

This presentation reviewed the author's recent doctoral work on how jurors in homicide trials comprehend and place weight on forensic science testimony. The data were collected over 24 months in Maine by interviewing jurors about the forensic science experts who testified at trials. The results of this research show that, from the juror's perspective, expert witness credibility influences a juror's determination of the reliability of the evidence presented. The research also highlights that the way the pattern evidence expert testified—e.g., in a narrative form, using demonstrative aids—influenced how well the juror understood the evidence and, in turn, how reliable they determined the evidence to be.

Scope: Forensic scientists and, in particular, pattern examiners who testify in jury trials

Objective: To inform practicing forensic scientists about how jurors determine credibility in an expert witness and the reliability of forensic science evidence. Credibility and reliability are two key factors that influence how much weight jurors place on testimony. The presentation aims to empower pattern experts to take time to teach the jury how they came to their conclusions and to use demonstrative aids where possible.

Brief narrative: The judicial system calls upon expert witnesses to testify in court when complex or specialized knowledge, beyond that of the lay person, is needed to interpret the evidence. Expert witnesses explain the meaning of the evidence and can express their opinion of its significance within the context of the circumstances of a given case. In a jury trial, it is the responsibility of the jury to listen to, assimilate, comprehend, and place the appropriate weight on the expert testimony in their final decision-making.

Knowledge of how juries comprehend forensic science evidence and how this type of testimony influences decision-making is sparse. The US National Academy of Science report, *Strengthening Forensic Science in the United States: A Path Forward* (National Research Council, 2009), called upon the greater forensic science community to address weaknesses in the forensic science disciplines. One of the weaknesses highlighted was a lack of research into how juries use and comprehend forensic evidence. This study aimed to investigate the perceptions jurors have of expert witness testimony, delivered as oral evidence, by prosecution forensic scientists in homicide cases in the United States. Using a mixed-methods approach and both questionnaires (n=29) and direct one-on-one interviews (n = 22), data were gathered from juries after they had completed jury duty in one of nine homicide cases. How jurors determined the credibility of an expert witness and their views of the reliability of evidence presented to them by the witnesses they were exposed to were explored. The importance of forensic evidence in the jury decision-making process and the tensions between the expertise and experience of the witness were also explored, together with jurors' views of technology and understanding of the science presented. The role of the use of narrative in evidence was explored in particular through the use of demonstrative aids to explain the scientific evidence. Jurors described

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that deeper understanding resulted from such testimony. Jurors also suggested that the expert witness's education and years of experience were favored over certification and laboratory accreditation and that the credibility of the witness was reported to be a key factor in the juror's acceptance that the evidence presented was reliable. This work also exposed the degree to which jurors evaluate the reliability of forensic science evidence based on the credibility of the expert witness.

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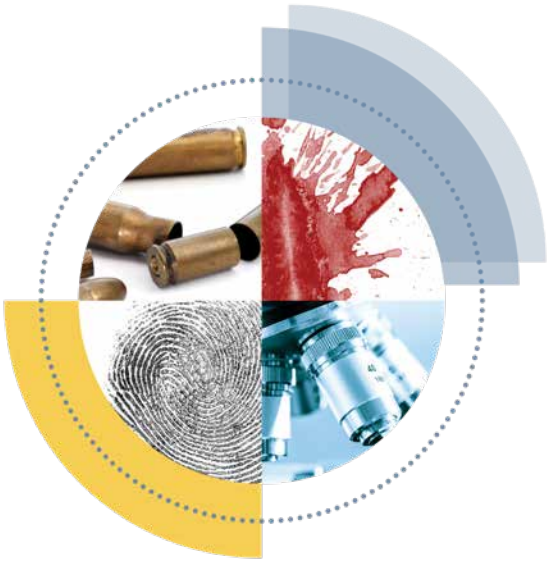
IMPRESSION & PATTERN EVIDENCE BREAKOUT SESSIONS



Status Update on the Development of a 3D Scanning and Analysis System for Cartridge Cases

Ryan Lilien, PhD

Cadre Research

The ability to measure and compare 3D surface topographies is emerging as a powerful new tool within firearm and toolmark analysis. When accurately measured, these topographies represent a one-to-one geometric mapping between the scanned digital surface and the actual physical surface. Over the past few years, and supported in part by grants from the National Institute of Justice (NIJ), we have developed a hardware system for acquiring micron-scale surface topographies and software tools for the visualization and analysis of these surfaces. Our system is now in use by several forensic laboratories, and many of the ideas we initially introduced are being adopted by other scanning systems. In this presentation, we reported on our groups' recent progress in three main areas.

First, we described our core imaging technology, which is based on an improved version of photometric stereo. Our method uses a gel-based sensor pad to remove the influence of surface reflectivity on the imaging process. The setup allows micron-scale scans to be acquired within minutes. Acquired scans are brought into our analysis software for visualization and comparison.

Second, we described our work in virtual microscopy, which is the examination of digital representations of objects rather than the physical objects themselves. Virtual microscopy offers many novel uses to the forensic examiner, including remote data sharing/collaboration, visualization, access to historic casings, annotation of cartridge case surfaces, verification, and proficiency testing. We described our work to validate virtual microscopy, which involved 56 examiners at 15 laboratories and two proficiency-style test sets.

Finally, we discussed our work developing a statistically grounded comparison function. This function identifies geometric similarity between two surface topographies and quantifies the identified agreement to compute a statistical match probability. Such a function allows an examiner to supplement their identification or elimination conclusions with a statement regarding false-match probabilities.

In summary, over the past several years, we have developed a fast, accurate, and economical system for the 3D imaging of cartridge cases. The 3D surface scans produced by systems like ours are quickly becoming a valuable resource for the toolmark examiner. The presented work demonstrates the feasibility of our method and represents an important step toward validating this new technology for use in firearm and toolmark examination.

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Fracture Mechanics-Based Quantitative Matching of Forensic Evidence Fragments: A) Methodology and Implementations

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United States Department of Energy Ames Laboratory

The matching process can be subjective and reliant on operator judgment, and numerically quantifying the confidence in the match decision is not possible. Here, we show that the principles of fracture mechanics can be combined with statistical learning tools to provide an automated, data-driven approach for obtaining the match probability. Our developed methodology uses the quantitative description of the microscopic features on the fracture surfaces, which we establish as unique and informative regarding the fracture mechanism, to not only classify candidate fracture pairs with very high accuracy but also quantify the probabilities of these matches.

Scope: This presentation summarized a framework for objectively matching the fracture surfaces of brittle materials. The proposed framework investigates the fundamental scientific basis for forensic analysis of fractured and torn surfaces, derived from the quantitative details of the material microstructure and the established concepts of deformation mechanisms, fracture process zones, and their scaling, in the field of fracture mechanics. The framework has the potential for forensic application across a broad range of fractured materials and/or toolmarks with diverse textures and mechanical properties.

Objective: To develop a methodology utilizing the quantitative description of the microscopic features on the fracture surfaces, which we establish as unique and informative regarding the fracture mechanism, to not only classify candidate fracture pairs with very high accuracy but also quantify the probabilities of these matches. Spectral analysis of 3D fracture surface topography measurements is employed to associate or differentiate fracture surfaces for physical comparisons. We incorporated an understanding of material failure mechanisms (developed in the field of fracture mechanics) with digital image analysis to construct protocols for the association (or exclusion) of pairs of surfaces.

Narrative:

Introduction. The basis for physical matching is the assumption that an indefinite number of matches exist along the fracture surface. The irregularities of the fractured surfaces are considered to be unique and may be exploited to individualize or distinguish correlated pairs of fractured surfaces. For example, the complex jagged trajectory of a macro-crack in the forensic evidence specimen can sometimes be used to recognize a "match" by an examiner or even by a layperson on a jury. However, fracture experts need experience, understanding, and judgment to make reliable examination decisions using comparative microscopy and tactile pattern match. The microscopic details imprinted on the fracture surface carry considerable information that could provide quantitative forensic comparisons with higher evidentiary value. The focus of this work is on developing a fracture mechanics-based analysis with quantified match probabilities for forensic physical matches for a variety of materials.

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Methodology. The rough and irregular metallic fracture surfaces carry many details of the metal microstructure and its loading history. Mandelbrot, Passoja, & Paullay (1984) first showed the self-affine scaling properties of fractured surfaces to quantitatively correlate the material resistance to fracture with the resulting surface roughness. The self-affine nature of the fracture surface roughness has been experimentally verified for a wide range of materials and loading conditions. A key finding is the variation of such surface descriptors when measured parallel to the crack front and along the direction of propagation. Additionally, it was observed that while self-affine characterization of the crack roughness exists at a scale length smaller than the fracture process, the surface character becomes more complex and non–self-affine at larger length scales.

Motivated by these observations, it can be speculated that a randomly propagating crack will exhibit unique fracture surface topological details when observed from a global coordinate that does not recognize the crack propagation direction. This work explores the existence of such uniqueness of a randomly generated fracture surface at some relevant length scales. The uniqueness of these topological features implies that they can be used to individualize and distinguish the association of paired fracture surfaces. Our hypothesis is that the microscopic features of the fracture surface possess unique attributes at some relevant length scale that arise from the interaction of the propagating crack-tip process-zone and microstructure details. The corresponding surface roughness analysis of this surface using a height-height correlation function shows promise of individuality. These microscopic feature signatures should exist on the entire fracture surface as it is influenced by three primary factors: the material microstructure, the intrinsic material resistance to fracture, and the direction of applied load. This work explores the existence of such a length scale and the corresponding unique attributes of the fracture surface. A statistical framework is developed to provide a basis for the quantification of error probabilities for the process.

Approach. Two sets, each consisting of nine knives from the same manufacturer and having an average grain size of dg = 25–35 μm were fractured at random. For clarity, we refer to the surface attached to the knife handle as the base and the surface from the tip portion of the knife as the tip. Each pair of fractured surfaces was imaged using a standard noncontact 3D optical interferometer (Zygo-NewView 6300). An extended set of nine topological images with a 550-μm field of view were collected on each fracture surface. The mathematical operator of two dimensional fast Fourier transform was applied to each image to calculate its spectral frequency distribution. For comparison, the spectra of a pair of images were correlated with each other within a banded radial frequency domain with ranges of 5–300 mm–1 using 2D statistical correlation. That is, we calculated the correlation between the spectra from corresponding images on the tip and base surfaces in different frequency bands. Image pairs for when the tip and base surfaces were from the same knife are true matches, while those pairs from when the tip and base surfaces were from different knives are true nonmatches. Correlation analysis showed clear separation (with generally lower values for the true nonmatches and higher values for the true matches) for the

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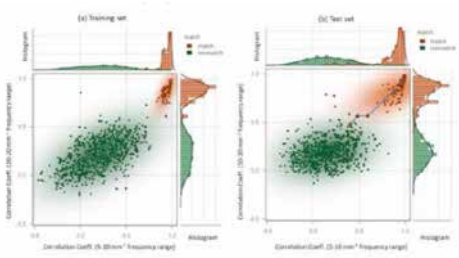
5–10-mm–1 and 10–20-mm–1 frequency band ranges, respectively, as shown in Figure 1 (side and top distributions in each figure). Beyond these frequency ranges, the correlation histograms of the true match and true nonmatch begin to be less distinctive from each other.

For the first set, Figure 1(a) shows complete true nonmatch separation in all paired correlations when both the 5–10-mm–1 and 10–20-mm–1 frequency ranges are considered together. In the second set, there is one image pair among the true matches that cannot be distinguished from the true nonmatches. However, when all nine image pairs (connected with a solid line) for this true match are considered, collectively, the values are distinctive enough to separate the true matches from the true nonmatches. This complete set of nine images is exploited to provide a decision rule to predict a true match and nonmatch with high accuracy.

Figure 1. Plot of correlations between the each of nine base-tip image pairs of the nine knives in the (A) first set and (B) second set of knives



Note: The plot is for correlations in the 10–20-mm–1 frequency range against those obtained in the 5–10-mm-1 frequency range. Colors indicate true matches and true nonmatches. In (A), all correlations from true matches are distinct from those of the true nonmatches when both frequency ranges are considered together. In (B), one correlation from a true match image pair cannot be individually separated from the correlations of the true matches but can be individually separated in conjunction with the other correlations from the eight other image pairs (to which it is connected by a line). The margins indicate the distribution of correlations at each frequency range and show that using only one frequency range leads to poorer discrimination between the true match and true nonmatch signatures.

Funding source: National Institute of Justice award No. 2015-DN-BX-K056

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Fracture Mechanics-Based Quantitative Matching of Forensic Evidence Fragments: B) Statistical Framework

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Scope: This presentation summarized a framework for objectively matching the fracture surfaces of brittle materials. The proposed framework investigates the fundamental scientific basis for forensic analysis of fractured and torn surfaces, derived from the quantitative details of the material microstructure and the established concepts of deformation mechanisms, fracture process zones, and their scaling, in the field of fracture mechanics. The framework has the potential for forensic application across a broad range of fractured materials and/or toolmarks with diverse textures and mechanical properties.

Objective: To develop a methodology using the quantitative description of the microscopic features on the fracture surfaces, which we establish as unique and informative regarding the fracture mechanism, to not only classify candidate fracture pairs with very high accuracy but also quantify the probabilities of these matches. Spectral analysis of 3D fracture surface topography measurements is employed to associate or differentiate fracture surfaces for physical comparisons. We incorporated an understanding of material failure mechanisms (developed in the field of fracture mechanics) with digital image analysis to construct protocols for the association (or exclusion) of pairs of surfaces.

Narrative:

Introduction. The basis for physical matching is the assumption that an indefinite number of matches exist along the fracture surface. The irregularities of the fractured surfaces are considered to be unique and may be exploited to individualize or distinguish correlated pairs of fractured surfaces. For example, the complex jagged trajectory of a macro-crack in the forensic evidence specimen can sometimes be used to recognize a "match" by an examiner or even by a layperson on a jury. However, fracture experts need experience, understanding, and judgment to make reliable examination decisions using comparative microscopy and tactile pattern match. However, the microscopic details imprinted on the fracture surface carry considerable information that could provide quantitative forensic comparisons with higher evidentiary value. The focus of this work is on developing a fracture mechanics-based analysis with quantified match probabilities for forensic physical matches for a variety of materials.

Methodology. The rough and irregular metallic fracture surfaces carry many details of the metal microstructure and its loading history. Mandelbrot, Passoja, & Paullay (1984) first showed the self-affine scaling properties of fractured surfaces to quantitatively correlate the material resistance to fracture with the resulting surface roughness. The self-affine nature of the fracture surface roughness has been experimentally verified for a wide range of materials and loading conditions. A key finding is the variation of such surface descriptors when measured parallel to the crack front and along the direction of propagation. Additionally, it was observed that while self-affine characterization of the crack roughness exists at a scale length smaller than the fracture process, the surface character becomes more complex and non–self-affine at larger length scales.

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Motivated by these observations, it can be speculated that a randomly propagating crack will exhibit unique fracture surface topological details when observed from a global coordinate that does not recognize the crack propagation direction. This work explores the existence of such uniqueness of a randomly generated fracture surface at some relevant length scales. The uniqueness of these topological features implies that they can be used to individualize and distinguish the association of paired fracture surfaces. Our hypothesis is that the microscopic features of the fracture surface possess unique attributes at some relevant length scale that arise from the interaction of the propagating crack-tip process-zone and microstructure details. The corresponding surface roughness analysis of this surface using a height-height correlation function shows promise of individuality. These microscopic feature signatures should exist on the entire fracture surface as it is influenced by three primary factors: the material microstructure, the intrinsic material resistance to fracture, and the direction of applied load. This work explores the existence of such a length scale and the corresponding unique attributes of the fracture surface. A statistical framework is developed to provide a basis for the quantification of error probabilities for the process.

Approach. We used machine learning methods to obtain a decision rule using the fracture surface images from one set of knives and used that to predict whether every base-tip sequence of image pairs indicated a match or a nonmatch. Our decision rule consisted of two stages: computing the probability that two specific aligned images match each other and then computing the probability that the base and tip match each other based on the results from the set of aligned images from that base and tip. Within each set of knives, the correlations within and frequency bands between aligned image pairs were computed to generate a set of correlations between all base and tip pairs in the set. For example, the frequency bands of the first image of the base of a knife were compared to the frequency bands of the first image of the tips of the rest of the knives in the set, and a similar process is followed for the other eight images for that base. Using the training set, a quadratic discriminant analysis classifier was trained to identify matching base and tip pairs on the set of correlations for the frequency range and a logistic regression classifier with a weakly informative prior was trained for the frequency range. These classifiers then produced a vector of 18 match probabilities for each base and tip pair. This was reduced to one dimension by projecting it onto the first principal component of the 18 probabilities for the set of base and tip pairs. A linear discriminant analysis classifier was then trained on this 1D projection to produce a final probability that the given base and tip pair is a match. The resulting classifier had perfect discrimination between matching and nonmatching base and tip pairs when applied on both the training and test set.

Funding source: National Institute of Justice award No. 2015-DN-BX-K056

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The Evaluation of the Joint Value of Paint and Toolmark Evidence Using Bayesian Networks

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Sam Houston State University

Tools are objects often used to access properties, break or open objects (e.g., cabinets or drawers), or hit an individual, as a weapon. Tools can impart indentations and/or dragged marks on the surfaces with which they come into contact. If painted, tools can shed paint debris, often in the form of chips or powders. Tools can also retain material debris from the surface exposed to the contact, such as paint, wood, or plastic. The clarity of marks, the size of the imprinted area, or the quantity of materials having transferred and persisted may be limited. The occurrence of these traces in low quality and quantity may considerably affect the evaluation of their evidential value. The joint value of toolmarks as well as architectural and tool paint was discussed in the context of different scenarios. Typically, the outcomes of the examinations of the two sets of material clues are offered separately. Paint debris may not even be considered for examination if high-quality toolmarks are recovered. The typical question addressed following comparative examinations involving both paint debris and toolmarks is whether questioned specimens originated from a given painted object. Toolmark examiners offer conclusions that range from identification, inconclusive, elimination, or unsuitable for examination. Trace evidence examiners tend to offer conclusions that follow an "association" scale (which correspond to a posterior probability from a Bayesian perspective) or to use limited conclusions such as "cannot be excluded" or "could come from." Should both types of evidence be examined and reported, their joint evaluation may be overlooked or insensibly left to the trier of fact without appropriate guidance.

This presentation considered typical cases in which the contribution of each piece of evidence is moderate (e.g., resulting in an inconclusive decision), in which one offers a strong evidential value and the other a weak one or vice versa, or in which the outcome of one piece of evidence does not agree with the other (i.e., dissonant evidence). When pertinent, the combination of these two types of evidence is addressed at the activity level as opposed to the source level. This means that the uncertainties related to the presence of such marks in a given location is addressed and not merely the uncertainties concerned with their origin. For example, in a scenario in which a toolmark is recovered on a window frame and microscopic paint flakes are recovered on a screwdriver, the following propositions may be considered: "The screwdriver was used to force the window frame" and "another tool was used to force the window frame." This pair of propositions screens and encapsulates the two sets of source-level propositions such as (a) "the toolmark was left by the screwdriver" and "the toolmark was left by another tool" and (b) "the paint flakes come from the window frame" and "the paint flakes come from another painted object."

The uncertainties related to the observations of paint and toolmark evidence types are treated by means of Bayesian networks. Bayesian networks are graphical models that allow the dissecting of a complex problem into simpler, though related, pieces. Bayesian networks can address uncertainties between dependent variables in an intuitive and natural way. Depending on the scenarios, toolmarks and paint debris may be assumed to be dependent in

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various ways. For example, in the absence of acquired characteristics, it cannot be guaranteed that the specifications of the paint attributes (e.g., color and detected chemical profile) are not related to the physical class characteristics of a tool (e.g., shape of blade and size, metal alloy composition). Also, it cannot be guaranteed that the acquired characteristics on a tool may not depend on the physical manufacturing characteristics of a tool or on the property of the paint to adhere to the surface of the blade of a tool and as a consequence to affect the creation of striae or other defects. In this presentation, we showed how Bayesian networks can provide insight to address questions involving these features and how they may be used to assess activity-level propositions in specific cases.

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Implementing 3D Virtual Comparison Microscopy into Forensic Firearm/Toolmark Comparison

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In 2012, the Firearms/Toolmarks Unit (FTU) of the FBI Laboratory began acquiring 3D instrumentation to determine whether this technology could be used to enhance the forensic pattern-based discipline of firearm/toolmark identification by providing objective information to establish the statistical significance and associated uncertainty of a conclusion. If successful, these technologies would not only provide an objective conclusion but possibly create efficiency in forensic casework with a high number of submitted components and provide a larger-scaled view of captured information for analysis and evaluation. Since that time, the FTU has acquired the following systems for evaluation: Sensofar-Confocal Interferometry and Focus Variation, Cadre Forensics-Topmatch GS 3D, Alicona-Infinite Focus, EvoFinder, and a GigaMacro. To assess these platforms, the FTU developed a validation plan encompassing a two-phase approach. Phase one included developing a method to assess the instruments' measuring capabilities and what type of standard could be used to collect that information, determining the collection parameters to acquire the image, and identifying the appropriate sample data sets for collection and evaluation. The initial data samples selected for evaluation included a previously distributed proficiency test that the FTU had used from 2003 to 2012 and three test sets assembled from the FBI Laboratory's consecutively manufactured slides and barrels collection. To ensure that bias was not introduced into the evaluation by the examiner performing in the virtual comparison, all of the samples acquired for scanning were renumbered and entered into the system by a proctor, and the instrument's algorithm was not displayed; thus, the participant would not have any additional influence. The outcome of these data sets demonstrated that 3D technology would be a viable operation for performing virtual comparisons on ammunition components, and the FTU began its final step of the validation process, which included previously analyzed casework samples. The first system to have this last step finalized was the Cadre Forensics-Topmatch GS 3D system. To ensure ground truth in the casework sample sets, known test fires were intermixed within the casework samples and were included in the examiner's evaluation. The examiners contributing to the casework assessment varied in their years of experience. To ensure sample anonymity, all samples were renumbered entered by a proctor, and comparison results were recorded on individual answer sheets, which were collected and retained. This presentation will discuss the implementation process, challenges encountered, proposed work flows, the preparation of Standard Operating Procedures, and the use of the technology in operational casework.

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"Congruent Matching"—Theory and Application in Forensic Image Identification

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National Institute of Standards and Technology

For more than 100 years, firearm and toolmark identification has been based on the visual comparison of toolmark images by a trained firearm and toolmark examiner. However, the scientific foundation of firearm and toolmark identification has been challenged recently by National Research Council (NRC) and President's Council of Advisors on Science and Technology (PCAST) reports (NRC, 2009; PCAST, 2016). In response, we developed a congruent matching cells (CMC) method for the objective comparison of impression toolmarks and evaluation of the weight of the evidence or the error rate (Song, 2013, 2015). The CMC method is based on the principle of discretization—it divides the compared topography image pairs into correlation cells and uses four identification parameters to quantify both the topography similarity of the correlated cell pairs and the pattern congruency of the registered cell pairs in x-, y-, and angular positions. The comparison metric is the number of CMC (i.e., the number of cell pairs that meet both the similarity and congruency requirements).

An initial test on breech face impressions of a set of 40 cartridge cases fired with consecutively manufactured pistol slides showed wide separation between the distributions of CMC numbers observed for known matching (KM) and known nonmatching (KNM) image pairs (Chu, Tong, & Song, 2013). Another test on 95 cartridge cases from a different set of slides manufactured by the same process also yielded widely separated CMC distributions, consistent with the first test.

In addition to the CMC method for breech face impressions, we have developed alternative methods based on congruent matching for other regions of interest on bullets and cartridge cases. The congruent matching cross-sections (CMX) method is proposed for firing pin image correlations (Zhang, Tong, Song, & Chu, 2016): the firing pin image is sliced into horizontal layers, yielding a cross-section profile for each layer. Three parameters are proposed for determining the similarity of the topography pairs: similarity of the paired profiles and their registration in the horizontal (angular) and vertical (or layer) positions. Validation tests using 40 cartridge cases of three different brands of ammunition fired from 10 firearms produced by three different manufacturers yielded clear separation between KM and KNM image pairs (Zhang et al., 2016).

The congruent matching profile segments (CMPS) method is proposed for striated toolmarks, such as those found on bullets (Chu, Song, Soons, & Chen, 2017): the captured 3D topographies on the land engraved areas (LEAs) are processed by striation edge detection. The resulting 3D striation signatures are compressed into 2D profiles for representing the individual characteristics of bullet LEAs. Each compressed LEA profile is divided into profile segments for accurate correlation using four identification parameters: the 2D profile similarity is quantified by cross-correlation function, and the congruency of profile segment patterns is determined by the twist angle, index number of the correlated LEAs, and series number of correlated profile segments at each LEA. A set of test bullets were fired from 10 consecutively manufactured gun barrels:

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10 pairs of KM bullets for training and 15 unknown bullets for tests. In total, 595 image pairs were correlated with the CMPS method: 46 KM and 549 KNM pairwise image correlations, each consisting of 6 × 6 land comparisons. The results of this initial test of the CMPS method show no false identifications or false exclusions (Chu et al., 2017).

We are also working on the congruent matching features (CMF) method for the correlation of complex features of firearm evidence, such as ballistics images with strong sub-class characteristics. The 3D topography images are divided into specific features of peaks and valleys by a central-line truncation method (Ott, Soons, Thompson, & Song, 2017), and those peak and valley features are correlated using the CMF method. A similarity map has been developed by the CMF method to identify and illustrate the similar and dis-similar regions on the correlated image pairs (Ott et al., 2017).

The large number of cell (or section, profile, and feature) correlations associated with the CMC (or CMX, CMPS, and CMF) method using multiple identification parameters facilitates a statistical approach to modeling error rates. We have developed an error rate estimation procedure based on the CMC method for breech face evidence identifications (Song et al., 2018).

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Estimating Error Rates of Firearm Identifications Using the CMC Method

Theodore Vorburger, PhD

National Institute of Standards and Technology

Marks left on cartridge cases and bullets by firearms may be used to identify those firearms. For many years, the determination of whether two cartridge cases or two bullets were fired by the same firearm has been conducted by experts through visual comparison of the toolmarks using 2D reflectance comparison microscopy. Recently, however, the application of areal (3D) surface topography measurement and analysis to firearm and toolmark identification has provoked much interest among forensic examiners, surface metrologists, and vendors of topographic microscopes. A key advantage of 3D topography measurement is that the respective images are less affected by experimental conditions, such as lighting, making them more amenable to objective numerical analysis. The key property to quantify here is toolmark similarity. Are the firearm toolmarks on two surfaces similar enough for attribution to the same source, and can we estimate the respective uncertainty?

The growth in research in this field has been helped by improvements in the measurement, analysis, and visualization of surface topography. We used confocal microscopy to acquire topography images of the breech face impression on 9-mm cartridge cases. We then used the congruent matching cells (CMC) method (Song, 2013) to identify same-source (matching) image pairs. The CMC method divides the reference image into correlation cells. Each cell is then registered to the cell-sized area of the compared image that has maximum topography similarity, as defined by the respective correlation coefficient. Four parameters are used to quantify both the topography similarity of the correlated cell pairs and the pattern congruency of the registered cell locations. An identification (declared match between images) requires a significant number of CMCs (i.e., cell pairs that meet all similarity and congruency requirements).

We initially applied the method to the breech face impression on cartridge cases fired from two different sets of consecutively manufactured pistol slides of the same brand finished using sand and bead blasting. The first set, which was assembled by Fadul, Hernandez, Stoiloff, & Gulati (2012), consists of 40 impressions from 10 slides yielding 780 image pairs: 717 known nonmatches (KNM) and 63 known matches (KM). The second set, which was assembled by Weller, Zheng, Thompson, & Tulleners (2012), consists of 90 impressions from 10 slides and five impressions from one additional slide that was not consecutively manufactured. The latter set yields 4,465 image pairs: 4,095 KNM and 370 KM pairs. For both sets, there is a significant separation of the CMC values between KM and KNM image pairs.

Estimating error rates for firearm evidence identification is a fundamental challenge in forensic science. To estimate the false-positive error rate for the samples described above, the KNM histograms are modeled by a binomial distribution with only one fitted parameter: the probability of a pair of KNM cells to be classified as a (false positive) CMC cell pair. For KNM comparisons, the underlying assumption of Bernoulli cell trials seems a reasonable approximation. Extrapolating the model to the region where the bulk of CMC values are observed for KM pairs yields extremely small predicted error rates for producing false positives. The underlying Bernoulli assumptions of independent

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cell trials and a constant cell trial success probability do not apply to KM comparisons and require modifications to the respective distribution models.

We are working to scale up the CMC analysis method and statistical models to realistic populations of firearms. We measured the breech face impression on test fires obtained from 9-mm semiautomatic pistol slides from four other brands manufactured using different methods. For all brands, the histograms for KNM image comparisons are consistently confined to small CMC values and are well described by the binomial distribution model, thus supporting the prospect for applying the models to larger populations and realistic case work. Our goal is to create a system for automated objective firearm identification, including a quantitative assessment of the strength of the evidence, to support the visual comparison of topography images by a trained expert.

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Objective Comparison of Striated Toolmarks Produced from Ten Consecutively Manufactured Cold Chisels Measured by Contact and Optical Surface Profilometry and Comparison Microscopy

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National Institute of Standards and Technology

This is the first scientific investigation to employ consecutively manufactured tools (chisels) to produce striated toolmarks whose contour profiles were measured by (1) contact stylus profilometry, (2) noncontact 3D optical profilometry employing infinite focus microscopic surface measurement, and (3) the quantitative consecutive matching stria (QCMS) method. Striated toolmarks were made pairwise in a controlled manner from 10 consecutively manufactured cold chisel blades. Comparison tests between toolmarks made in this manner have the best potential for producing microscopic agreement between two or more different tool sources, resulting in false-positive identification. The striated toolmark profiles were measured using contact stylus 2D profilometry (Form Talysurf) and noncontact optical 3D profilometry (Alicona). Profile similarity and differences of known matching (KM) and known nonmatching (KNM) toolmarks were compared using two mathematical methods: cross-correlation function (CCF) and the recently developed congruent matching profile segments (CMPS) method. Both 2D profile and 3D topography comparisons show a wide separation between KM and KNM CCF score distributions when the full-length profile comparisons were made. Similarly, large separations of KM and KNM score distributions were also the result of profile segment comparisons performed by CMPS. Replicas of the KM and KNM chisel toolmarks were also compared using comparison microscopy, and the similarity and differences were measured by the QCMS method. The results of these comparisons also demonstrate a wide separation of distributions between the QCMS "runs" in KM and KNM toolmark comparisons, and no KNM comparisons exceeded three consecutive matching stria. The score distributions were also examined in a subjective statistical manner for their theoretical estimations of matching probability and demonstrate an exceedingly rare probability of sufficient agreement that would result in false-positive identifications.

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Quantitative Methods for Forensic Footwear Analysis

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Given a questioned impression (crime scene) and a test impression (obtained from a shoe of interest), an important question to triers of fact is "did the shoe corresponding to the test impression also make the crime scene impression?" The 2009 National Academy of Sciences report and 2016 President's Council of Advisors on Science and Technology report state that forensic footwear identifications are largely subjective. This has raised questions about the reliability and scientific validity of footwear examinations. Both reports have expressed the need for quantitative assessments of footwear evidence using scientifically valid methods. In this talk, we presented an end-to-end proof of concept for a system that performs quantitative footwear impression comparisons. The system uses quantitative methods for identifying features present in questioned and known footwear impressions and metrics for summarizing the degree of correspondences and discrepancies among these features in the form of comparison scores. The system is meant to be used by footwear examiners during evidence evaluations by providing them with the comparison scores and other quantitative information to help place the scores in context. The goal is to provide more scientifically valid information for court cases and higher degrees of accuracy, repeatability, and reproducibility than today's methods.

The end-to-end system includes image feature extraction, feature-based matching, comparison score generation, and creation and analysis of score distribution charts and receiver operating characteristic (ROC) charts, which facilitate error rate assessment. We use simulated crime scene data, synthetic crime scene data, and test impressions to perform our experiments.

For feature extraction, we use a hybrid human/computer feature extraction step, followed by an automated quantification of the degree of correspondences and discrepancies between the impressions being compared. The hybrid feature extraction leverages the training and expertise of footwear examiners for the identification and extraction of potentially discriminating features from crime scene impressions. We demonstrate a graphical user interface (GUI) for extracting features and their local positions; the algorithm then refines the features using mathematical and optimization methods. We have implemented three methods for marking features on images: (1) manual-only mark up of geometric features, such as points lines, circles, and polygons; (2) automatic adjustment of these features to better fit the grey-scale gradient; and (3) automatic extraction of features based on manually extracted ones. We have implemented preliminary feature-based matching algorithms using graph theoretic approaches, including the maximum clique algorithm. These are used to generate comparison scores, which summarize the degree of correspondences and discrepancies between compared impressions. This step is fully automated; all results are repeatable and reproducible. We then create score distribution charts and ROC charts. Suppose we have a representative collection of known mated and nonmated pairs of impressions. The best scoring system will produce the greatest separation between the distribution of scores for mated pairs (say F_{mated}) and the distribution of scores for nonmated pairs (say, $F_{nonmated}$).

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Ideally, the distributions F_{mated} and $F_{nonmated}$ would be completely disjointed. That is, scores for mated pairs would never occur as scores for nonmated pairs and vice versa. We use the ROC metric to describe how successful a given scoring system is in ranking mated pairs ahead of nonmated pairs of impressions. Our goal is to develop comparison scores that have superior performance with respect to their ROC. Scoring procedures that result in a large true-positive rate at any given false-positive rate are of interest and are the better-performing procedures.

For applications to casework, the casework score obtained from matching the crime-scene image with the test impression is plotted on the score distribution charts to obtain reference percentiles. Suppose we have a collection of ground truth-known mated and nonmated impression pairs that are considered to be representative of impression pairs obtained under conditions similar to the current crime scene conditions. We will refer to such a collection as a case-relevant reference dataset. The meaning of the comparison score obtained for the casework pair of impressions is to be understood in the context of the mated and nonmated score distributions computed from this case-relevant reference dataset. Specifically, for a particular pair consisting of a crime scene impression and a reference impression, one can compute the comparison score and use the case-relevant reference dataset to determine what proportion of the distribution of mated scores equal or exceed this score and also what proportion of the distribution of nonmated scores equal or exceed this score. We can also choose other methods of evidence interpretation, such as score-based likelihood ratios. Such information, along with a careful description of the case-relevant reference dataset, can be used to help make weight of evidence assessments.

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A Comprehensive Research on Shoeprints RACs

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Introduction: Both the National Research Council (NRC) in 2009 and the President's Council of Advisors on Science and Technology (PCAST) in 2015 urged the forensic science community to put "more science into the forensic science." This is a very challenging task, and despite the significant effort constantly directed toward fulfilling this objective, this goal has not been fully accomplished. In the last decade, forensic scientists have been urged to use more scientific methods and change their methodologies to make forensic science more scientific.

Scope: The authors, together with CSAFE, are conducting the most comprehensive research done on shoeprint soles, focusing on collecting data in a meticulous way to create a database and algorithms that will result in great progress in shoeprint comparison.

Methods: This research began with the distribution of 120 pairs of two models of shoes in two sizes to volunteers (students at Iowa State University). Thus, samples of 30 similar shoes are being worn during a period of 1 year. Every month, a test impression is made from each shoe, and the degree of wear and the development of randomly acquired characteristics (RACs) is tracked.

The shoe sole images are captured using at least three methods:

1. Using the traditional method of fingerprint powder and sticky film
2. Using a shoe sole 2D scanner produced by EverOS (also available to National Institute of Standards and Technology [NIST] collaborators)
3. Using high-resolution 2D photography

We are also exploring the possibility of obtaining 3D images from the shoe soles at each measurement. At each measurement, we are scanning both the right and left shoes and perform the measurement in triplicate.

Conclusions: The outcome of this research, which remains in its first stage, was presented and could substantially influence how we analyze the results of shoeprint comparisons. This research could provide experts with new scientific and statistical tools to support the new standard demanded by the NRC and PCAST reports.

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The Effects of a Prior Examiner's Status and Findings on Lay Examiners' Shoeprint Match Decisions

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Introduction: Recent analyses of DNA exonerations reveal that errors related to forensic science can contribute to wrongful convictions (Dror & Bucht, 2012). Often these errors result from misrepresentation or misinterpretation of forensic evidence at trial, but in some cases, human errors known as "cognitive biases" can produce errors in forensic judgments (National Academy of Sciences, 2009). In addition to shedding important light on the potential effect of human bias on forensic examinations, the National Academy of Sciences report highlights the importance of collaborative research involving forensic scientists and academics in understanding and minimizing the role of interpretive bias and "sources of human error" across a broad range of forensic disciplines.

Studies suggest that a person's prior beliefs, motives, and situational context can influence how a piece of forensic evidence is perceived and interpreted during analysis (Kassin, Kukucka,Lawson, DeCarlo, 2013). One of the more widely researched forensic science disciplines with a well-documented vulnerability to cognitive bias is fingerprint analysis (Dror & Cole, 2010). However, previous research on bias in fingerprint analysis has focused on a single examiner's decision, largely ignoring the mandatory technical review step by a second examiner in the fingerprint examination protocol (Scientific Working Group on Friction Ridge Analysis Study and Technology, 2013).

Very few studies have systematically examined the effects of prior information on reviewers' decision-making during the verification stage of fingerprint analysis. The limited data available suggest that knowledge of a prior examiner's decision can influence an examiner's analysis of a fingerprint (e.g., Pacheco, Cerchiai, & Stoiloff, 2014). Langenburg et al. (2009) examined the importance of the source of prior information to explore whether a status difference could influence decision-making during the verification stage. Results suggested that when prints were from a different source, "inconclusive" responses increased when participants were aware of a prior examiner's decision relative to a control condition that received no information about a prior decision. This effect was "stronger" when participants were novices at fingerprint analysis compared with experts. However, participants were also provided with additional information about the prior examiner's justification for each decision, complicating the interpretation of the findings and underlying theoretical mechanisms.

In addition, laboratory studies have drawn criticism from practitioners for using novice evaluators (e.g., student participants) and stimuli arguably beyond their level of experience and training (e.g., fingerprint, handwriting, voice comparison; Kukucka & Kassin, 2014; Smalarz, Scherr, & Kassin, 2016), limiting the generalizability of findings to real-world contexts.

Scope and objectives: To address this limitation of prior research and to expand on the understudied effect of the technical review step, the present study examines the potential bias associated with the technical review step using shoeprint comparisons, stimuli that were used to screen potential applicants for firearm and tool mark positions at the Miami-Dade Police Department

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Forensic Services Bureau (MDPD FSB). Thus, using stimuli appropriate for novice evaluators in a controlled laboratory setting, the present study examines how knowledge of a prior examiner's conclusion (in the absence of the prior examiner's reasoning) and knowledge of the prior examiner's level of experience affect lay reviewers' evaluation of shoeprint comparisons. This allowed the researchers to test for cognitive bias in the technical review process using a controlled analog lab-based paradigm.

Method:

Design. The study employed a 4 (previous decision type: match vs. nonmatch vs. inconclusive vs. none) by 3 (prior information: forensic expert vs. student vs. anonymous) by 2 (stimuli type: match vs. nonmatch) mixed between-within participants design, with repeated measures on the last factor.

Materials and procedure. The shoeprint comparison test was developed by the MDPD FSB and consists of 20 footwear impressions. Upon entering the lab, student volunteers were told that the purpose of the study was to assess students' performance on a stimuli comparison task that is commonly used as an entrance exam for forensic examiners. Participants were seated in front of a computer and were instructed that they were about to view a series of shoeprint pairs that had been previously assessed. For each pair, they were asked whether the two stimuli were a match, nonmatch, or not sure/inconclusive. After each comparison, they were asked for the confidence in their decision on a scale from 1 to 7 and to rate the difficulty of the task on a scale from 1 to 7, with lower numbers indicating less confidence/difficulty. Participants were randomly assigned to one of three prior information/source conditions: receive information about a prior decision made by a forensic expert, receive information about a prior decision made by another student, or receive information about a prior decision made by another person (status of person was not given). For participants in the prior information conditions, the prior decision was either identified as a match by the prior examiner (correctly and incorrectly so), a nonmatch (correctly and incorrectly so), or inconclusive (all incorrectly so as ground truth is known), or participants were not given any information regarding previous decisions. Finally, participants answered demographic questions and were debriefed.

Results: Preliminary data on 60 participants suggest that the type of decision made by the prior examiner (i.e., match, nonmatch, inconclusive, or none) influences the accuracy of the second examiner's decision, $F(3,51) = 3.03$, $p = .038$. Accuracy was defined as the number of correct decisions (i.e., deciding it was a match when it was, in fact, a match) divided by all possible decisions. When a prior examiner deemed the pair inconclusive, the second examiner was significantly less accurate (40 percent accurate) compared with when the prior decision was a nonmatch (73 percent accurate) or no information was given (77 percent accurate).

Discussion: This study design enables testing for cognitive bias in a controlled lab setting without losing applied relevance. Preliminary data suggest that knowledge of a prior examiner's conclusion may bias stimulus analysis, especially if the prior examiner's decision was inconclusive.

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Generalizing Across Forensic Comparative Science Disciplines

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Scope: To discuss how natural patterns cannot be repeated, how unnatural patterns can be repeated, and how forensic comparative science needs persistency of both types of patterns to conduct meaningful examinations. By considering objects with generalized descriptions of repeated or unique features, comparative science disciplines can more easily come together under one umbrella of examination processes and results.

Objectives: To demonstrate how firearm/toolmark, shoe/tireprint, friction skin, documents, biometrics, and other comparisons-of-things disciplines can use the same attitude about and approach to their examination process.

Brief narrative: Natural patterns cannot be repeated. Unnatural patterns can be repeated. This discussion will present how using a common approach to the examination of things will work across disciplines in forensic comparative science.

Introduction. The presentation will discuss the commonalities across disciplines and how the disciplines can be considered as being subsets of the examination of shapes.

Methods. The presenter will discuss the commonalities and then depict branching off for specific aspects of a discipline.

Approach. The presenter will describe commonalities across disciplines and demonstrate a flowchart depicting how commonalities can be shared. Then, idiosyncrasies within a specific discipline will branch off that flowchart.

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Sufficiency and Complexity Factors in Handwriting Examination

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In this presentation, we explored and discussed the issues associated with the use of an automated handwriting verification system to characterize the relationship between handwriting complexity and the so-called likelihood of a chance match. This work focused on integrating an automated system with the recently developed Modular Approach for Handwriting Examination. The preliminary statistical results were illustrated with a convenience sample of handwritten documents collected by the Counterterrorism and Forensic Research Unit of the Federal Bureau of Investigation (FBI) Laboratory Division. The statistical suggestions were evaluated and discussed using a separate collection of writing samples from Dr. Mohammed's practice.

Forensic document examiners (FDEs) are often tasked with comparing handwriting to contribute to determining whether there is common writership between two sets of handwritings, normally designated as "questioned" and "known." The examination is conducted by a comparison process in which features of both sets of writing are extracted, examined, and evaluated for differences and similarities. Similarities, in general, indicate one writer. However, to judge the strength of the similarities in support of one writer, the FDE must also make a judgement on whether, and how often, such similarities are expected if the handwriting samples are the product of two writers.

In the first part of the examination, the FDE has to make a determination as to whether or not one or both sets of handwriting contain sufficient information in terms of amount and complexity for a meaningful comparison to be made. However, in the handwriting examination literature, sufficiency and complexity data are lacking. Different examiners may express a range of opinions concerning whether or not the quantity of known and questioned writing is insufficient for a comparison. This decision is usually expressed in terms of the perceived complexity in the documents submitted for comparison. To date, there are no empirical data showing how comparing varying amounts of handwriting affects the reliability of FDEs or, indeed, if there is a threshold where the FDE's decision becomes unreliable.

According to the modular approach to handwriting comparison, the amount of skilled writing and relative frequency of similarities between writing from different writers (also known as the likelihood of a chance match) have a hypothesized inverse linear relationship. One of the complicating factors is the sufficiency determination in the modular approach, which is inherently subjective. Consequently, decisions may vary widely between examiners. In this study, we use an automated system to examine and compare varying amounts of handwriting, where the relative frequency of similarities between writing from different writers is studied as a function of the number of words in a document. The handwriting samples provided are compared in pairs. The results will suggest when a sufficient comparable amount material is available and determine when the material is complex enough to provide the relative frequency of similarities for a chosen threshold.

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This research will result in a potential uniform baseline of sufficiency and complexity for FDEs when comparing the same evidence, which may result in more reliable conclusions between and within FDEs. The comparison methods used include a Poisson process, (corrected) chi-square classifier, Kullback-Leibler distance, and Dirichlet multinomial likelihood ratio, which are applied to the set of features extracted by the FLASH ID system on a set of handwritten documents collected as a convenience sample. The likelihood of a chance match is estimated for each comparison method using a newly developed, statistically rigorous methodology. In this talk, we explored the potential constraints for this study, including the automated system by itself, the chosen threshold, and the comparison methods used by the automated system, which may use different criteria than those used by FDEs. Although the methodologies may not be directly transferable to FDEs, they do provide data currently lacking in the FDE literature.

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Deep Learning in Handwriting Comparison

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Deep learning is an approach to artificial intelligence in which feature representations of the world are learned automatically rather than determined by humans. Deep learning methods are in contrast to traditional machine learning algorithms, which require human-crafted feature engineering. Because deep learning algorithms work on high-dimensional raw inputs, more information is kept, the chance of finding better features is enhanced, and better generalization to unseen data is possible. In impression evidence analysis, such as handwriting examination, human experts use years of training to extract features from raw data. Visually extracted subtle features, from known and questioned documents, are used to determine whether they have the same writer as the source. Although deep learning methods have outperformed other algorithms on the task of recognizing handwritten characters, their use with the handwriting comparison task remains to be explored. The goal of this research is to apply deep learning methods to extract representations from handwriting images. Because both spatial and temporal features must be extracted, the task is challenging. The deep learning architectures we are exploring include convolutional neural networks (CNNs), stacked auto-encoders, and recurrent neural networks (RNNs). The end-goal is to incorporate these architectures into an end-to-end system for handwriting comparison. In this paper, we presented preliminary results with CNNs and auto-encoders.

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Using Eye Tracking to Understand Decisions by Forensic Latent Print Examiners

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A variety of studies have evaluated the latent print examination process (e.g., Hicklin et al., 2011; Hicklin, Buscaglia, & Roberts, 2013; Ulery, Hicklin, Buscaglia, & Roberts, 2011, 2012; Ulery, Hicklin, Roberts, & Buscaglia, 2014a, 2014b, 2016, 2017), but relatively little research has addressed the fundamental basis of this visual task: how examiners use their eyes to accomplish these tasks and what visual information guides the examination process (Busey et al., 2011; Busey, Swofford, Vanderkolk, & Emerick, 2015; Busey, Yu, Wyatte, & Vanderkolk, 2013; Parada et al., 2015). This presentation will discuss the results of a study conducted to gain a greater understanding of how latent print examiners perform analysis and comparison tasks and of why examiners make different determinations. By asking examiners to annotate or mark up their work, some understanding of the information those examiners relied upon in making their determinations has been gained, but this is limited to the information they felt was worthy of annotating. Eye gaze information can facilitate better understanding the factors that lead to differences in examiners' interpretations and, ultimately, their conclusions.

Eye-tracking technology was used to monitor examiners as they performed their tasks to learn what visual information they used and how they worked with that information. Eye tracking allows us to determine not only how examiners differ in the features they look at in the images, but also how they aggregate information from those images, that is, using both spatial and temporal aspects of eye tracking. Analyses of why some examiners make inconclusive conclusions when others exclude or individualize will provide information that can be used to improve the reliability of the latent print comparison process, particularly for more challenging comparisons.

In this study, over 130 hours of eye gaze information were collected from 121 practicing latent print examiners as they performed over 2,000 fingerprint comparisons and over 1,200 other tasks designed to isolate specific behaviors that arise during comparison. The latter tasks included ridge counting, ridge following, and searching for a designated feature group ("find the target") in a comparison print. Eye gaze was sampled at a rate of 1 KHz using a camera and infrared illumination. The raw data were calibrated, partitioned into saccades (rapid eye movements) and fixations (eye movements with median duration = 0.27 s), and mapped onto image coordinates for subsequent analysis. Examiner annotations from previous research studies were available for the majority of the comparisons.

The presentation discussed how eye behavior is associated with examiners' determinations, including the extent to which eye behavior can explain erroneous determinations (false positive and false negative conclusions) and nonconsensus determinations (conclusions that differ from the majority of examiners). The presentation also discussed how eye behavior is affected by the difficulty of comparisons and how the presence or absence of visual context affects eye behavior. The results of this study reveal explanations for how some errors occur. The presentation described how examiners use information

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in the latent print and how that relates to comparison efficiency and risks of misinterpretations. Variability in the eye-tracking data and issues in the interpretation of these data that will be important to future research were discussed.

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Thematic Trends of Latent Print Examination Criticisms and Reports

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In 2009, the National Academy of Sciences (NAS) released a report entitled, *Strengthening Forensic Science in the United States: A Path Forward*. Largely the first of its kind in the United States, this report brought to light many gaps within the forensic sciences that were not previously realized within the forensic science practitioner community. Since that time, similar reports—such as the 2012 *Latent Print Examination and Human Factors: Improving the Practice Through a Systems Approach*, published by the National Institute of Standards and Technology (NIST) in conjunction with the National Institute of Justice (NIJ), and the report released in 2016 by the President's Council of Advisors on Science and Technology (PCAST) entitled *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*, and the American Academy for the Advancement of Science's (AAAS's) 2017 report entitled *Forensic Science Assessments: A Quality and Gap Analysis—Latent Fingerprint Examination*—cover similar elements relating to assessing gaps within the forensic disciplines and, specifically, throughout forensic latent print examinations.

Over the last decade, the forensic science community (researchers, policy makers, practitioners, and other stakeholders) has taken strides to address the criticisms brought forth by these broad reviews of the discipline. Despite these efforts, and as more reports are released, some commonalities among the criticisms persist. This presentation provided a broad summary of the thematic trends of these reports as they currently pertain to latent print examinations and how the community at large has responded to these criticisms. The intention of the presentation is to initiate a dialogue and encourage the practitioner community to undertake a candid evaluation of these criticisms and identify the true gaps in current practices. With this perspective, we can take a more proactive approach to address these gaps moving forward.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the US Department of the Army or US Department of Defense.

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Statistical Error Estimation for an Objective Measure of Similarity to a Latent Image

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The research project is a 1-year effort funded by the National Institute of Justice (NIJ) and started on January 1, 2018. The research project is addressing two key issues raised in *Strengthening Forensic Science in the United States: A Path Forward*. This presentation introduced and demonstrated the computation of an objective measure of similarity between a latent image and an exemplar image that is largely automated and requires no minutiae markup. The objective measure addresses the report statement that, "the assessment of latent prints from crime scenes is based largely on human interpretation." Furthermore, the objective measure addresses the report statement, "Clearly, the reliability of the ACE-V process could be improved if specific measurement criteria were defined." The research goal of the project is to provide a statistical assessment of the rarity of the objectively measured similarity to a latent image for any case exemplar. The rarity statement is expressed in the context of an atypicality index relative to measured similarity to the latent image for known nonmate exemplar images. Atypicality is a statistical concept that addresses many questions pertaining to forensic science; for instance, "does a case exemplar image belong to a specified population of nonmates to the latent image?" This research will provide valuable products for forensic science researchers who study the interpretation of evidence and inference concerning the source of a trace of unknown origin. For a latent image, the research project is computing the objective similarity measure for all exemplars in a very large set of known nonmate images as a basis for complex statistical analyses that will define an atypicality index. The research is validating the utility of the atypicality index for supporting forensic science decision-making by assessing risks associated with alternative decisions. This project's quantification of decision error risk addresses the *Path Forward Report*, which states in its summary, "Although there is limited information about the accuracy and reliability of friction ridge analyses, claims that these analyses have zero error rates are not scientifically plausible."

The research project uses the technology of a novel latent image examination tool to create a nonminutiae based objective measure of the similarity between an exemplar image and a latent image. This tool was described in detail in a 2014 Forensic Science International article (Gantz, Gantz, Walch, Roberts, & Buscaglia, 2014), and it was demonstrated at forensic science meetings in 2015 (Gantz et al., 2015a, 2015b). The proposal for this project provided evidence that the objective measure being used in this research is very accurate when applied to the Latent and True-Mate Images from the National Institute of Standards and Technology (NIST) Special Database 27 (SD27) Latent Data Set.

The project is also using the SD27 Set to demonstrate that current technology can compute a nonminutiae based measurement of similarity together with an associated error statement concerning that measurement. The project is producing and evaluating statistical models based on each of the Good, Bad, and Ugly Latent Images from the SD27 Set. The presentation will include preliminary computational results that support the promise of the research.

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The research utilizes the LatentSleuth workstation, which requires minimal manual processing of the latent image by a latent fingerprint examiner and then automatically provides distortion-adjusted overlays (Warps) to arbitrarily large sets of exemplar images. The LatentSleuth Workstation includes a very sophisticated toolbox that supports latent fingerprint examiners during Comparison. LatentSleuth is currently being evaluated by crime laboratories as a tool for increasing the efficiency of latent fingerprint examiners in the Analysis and Comparison phases of latent examination. The LatentSleuth technology is utilized to build a Latent Enrollment Process that is used to define an Objective Measure of Similarity to a Latent Image for an arbitrary exemplar image.

The research project focuses on in-depth statistical analysis on a very large body of Objective Similarity Measurement data, which are generated by applying the Latent Enrollment Process to the images in the SD27 Latent Data Set. The statistical assessments of the rarity of true-mate Similarity Measurements are the responses to the Path Forward Report introduced above. This presentation demonstrated the method of modeling the spurious similarity that nonmate exemplar images can exhibit to a particular latent image. Historical development stages of the modeling of spurious similarity have been presented by the researchers at both forensic science and statistics conferences (Gantz, 2012a, 2012b, 2015; Gantz, Walch, Gantz, & Miller, 2013).

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Occurrence and Utility of Latent Print Correspondences That Are Insufficient for Identification

David Stoney, PhD

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Latent prints that have insufficient characteristics for identification (NVID) often have discernable characteristics that could form the basis for lesser degrees of correspondence or probability of occurrence within a population. Currently, those latent prints that experts judge to be insufficient for identification are not used as associative evidence. How often do such prints occur? What is their potential value for association? Would they actually impact case investigations or prosecutions in a useful way? The goal of the present project is to make a reasonable measurement of the occurrence and usefulness of latent print correspondences that are insufficient for identification.

Current program objectives (Phase I) are to

- Collect 1000+ latent prints from casework, representative of current practices, with clear Level 2 ridge detail but that fall below the threshold "of value for identification."
- Under reasonable, well-defined assumptions and well-defined currently available methods, measure an expected maximum associative value (selectivity) for each of these latent prints.
- Categorize the rates of occurrence and associative value by the type of case (violent crimes vs. property crimes) and by currently available, objective measures of latent print quality.
- Use the findings, along with input from key constituencies, to design the scope and specific details for Phase II: determining, under reasonable assumptions and specific case contexts, the potential contribution of these prints to actual criminal prosecutions.

This presentation will give results from Phase I and discuss the scope and details of Phase II.

Using six donor forensic science laboratories, 1,717 NVID latents from 1,024 cases have been collected. Each latent print was screened by the principal investigator and re-assessed by a highly qualified, certified latent fingerprint examiner with respect to the NVID decision and probable number of Level 2 minutiae. Approximately 54 percent of the latent prints collected have met program requirements.

Measurements of associative value were made using an expected score-based likelihood ratio (ESLR). Auto-encoding of minutiae was performed using a SAGEM-Morpho Light-Out system in version 10. Quality maps for latent prints were obtained using the Universal Latent Workstation (ULW v6.4.1 with LQMetrics). Auto-encoded minutiae were accepted only for contiguous regions of the latent print showing higher quality (Quality 2 and above). Similarity scores were computed using a Morpho DMA equipped with a matcher in version 9.

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Measurements are underway. To date, most prints (69 percent) show an ESLR with weight of evidence between 103 and 106. None of the NVID latents meeting program criteria showed an ESLR lower than 103.

This work provides, for the first time, a measurement of the occurrence and associative value of NVID latents in casework. The actual usefulness of these prints depends on the case context. In Phase II, we will be working with investigators, prosecutors, and crime laboratories to study prints found in well-defined case contexts. Phase II will answer whether, how often, and to what degree associations from these latent prints could answer questions of relevance within specific case contexts.

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A Bayes Factor for Fingerprints, Using a Modified Approximate Bayesian Computation Approach

Jessie Hendricks, MS

South Dakota State University

Many scholars have advocated the use of the Bayes factor to quantify the weight of forensic evidence. However, issues arise in evaluating the Bayes factor for fingerprint evidence (and many other forensic evidence types) because of the complexity of the mathematical characterization necessary to capture the information contained in the evidence. For example, a friction ridge pattern is commonly characterized by heterogeneous high-dimensional random vectors containing information on minutia locations and spatial relationships, minutia types, and minutia orientations.

The difficulty in evaluating the Bayes factor lies in the necessity to assign probability distributions to these complex random vectors. Many methods that avoid directly modeling the distribution of fingerprint characteristics have been proposed, although none have been accepted in practice.

This research revisits the methods proposed by Neumann, Evett, and Skarrett (2012) to assign a Bayes factor for fingerprint evidence by using an Approximate Bayesian Computation (ABC) algorithm previously developed for use in population genetics.

The ABC algorithm results in an approximate Bayes factor for model selection. Here, we have adapted the ABC algorithm for the fingerprint setting where each model describes a different proposition for how a latent print was generated. For example, the first proposition might be that a given individual left the trace, while the second proposition might be that a random person from a relevant population left it. The ABC Bayes factor can be assigned without defining a probability distribution for the random vectors characterizing fingerprint evidence. Instead, many pseudo-fingerprints are generated with respect to each of the proposed models. Using a specially designed measure of distance between the mathematical characterizations of two fingerprints, distances are calculated between the latent print and each of the generated pseudo-fingerprints. Intuitively, small distances correspond to pseudo-fingerprints that are "similar" to the latent print.

In a similar fashion to Neumann et al., the original ABC algorithm proposes defining a similarity threshold such that distances less than that threshold correspond to pseudo-fingerprints that are "similar" to the trace, and distances greater than the threshold correspond to dissimilar pseudo-fingerprints. The ratio of the number of pseudo-fingerprints generated under each model that are considered "similar" to the unknown latent print is used as a proxy for the Bayes factor.

Issues with the choice of the similarity threshold have been recognized and documented in the literature on ABC. We propose a novel approach to address this issue, based on a property of the receiver operating characteristic (ROC) curve that allows us to remove the need to choose a similarity threshold in the algorithm. The first derivative of the curve can be evaluated near zero and used to assign the Bayes factor for the two considered propositions.

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To test the performance of the modified ABC algorithm for assigning a Bayes factor for fingerprints, we have conducted a large-scale experiment that considers separately each of the following as the latent print donor from the first proposition: the true source of the latent print, the closest nonmatching finger from a large database (4 million fingerprints), and a finger from a random individual in the database. In each of these cases, a relevant subset of individuals in the database was used as the population considered in the second proposition. By testing in each of these settings, we could confirm that the model produced an ABC Bayes factor that consistently provided support for the correct proposition.

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Assessing and Reducing Variability in Friction Ridge Suitability Determinations

Heidi Eldridge, MS

RTI International

Variability within and between examiners on value decisions has been well-documented, but what factors most influence decision-making? Can variability be reduced? And is the suitability decision more nuanced than a binary value/no value response?

This talk described ongoing research to understand how examiners reach suitability decisions, explore the use of multiple scales of value for different applications, and develop a software tool to reduce variability in suitability decisions.

A white box study involving over 100 latent print examiners has collected data on the information examiners believe is most diagnostic in reaching their decisions and has asked them to render suitability decisions along four suitability scales: value, complexity, Automated Fingerprint Identification System (AFIS) quality, and difficulty. Preliminary results that characterize the relationship between diagnostic factors and suitability decisions will be shared. These data will be combined with objective clarity and rarity data in the second phase of the project to develop a software tool to reduce variability in suitability decisions.

One hundred latent fingermark images were selected in a pseudo-random draw from a database containing over 1,600 casework impressions of varying quality. From these 100 images, each participant was presented with 30 images such that individual participants viewed different marks, and each mark was viewed by between 26 and 41 participants. Over 100 participants completed the study.

In the white box phase of this study, participants were asked to use a Picture Annotation System (PiAnoS) web interface to view and analyze each of the 30 images. For each image, participants were asked to annotate only the information that they noted and considered in making their suitability decisions. As this was not a test of visual acuity but of decision-making, participants were specifically instructed not to annotate everything they could see but only those things that factored into their decisions. Tools were provided for annotating minutiae type and confidence, incipient ridges, pores, target groups, and diagnostic minutiae clusters. Participants were also invited, but not required, to use quality mapping tools.

After completing their annotations, participants were asked a series of questions about their observations of pattern type, clarity, distortion, and level 3 detail and how they impacted their decisions. They were further asked to render a suitability decision along each of four scales: value, complexity, AFIS quality, and difficulty.

Descriptive analyses were performed on the data to describe the relationships between annotated variables and the suitability decisions that were reported. Future phases of this research will use machine learning to identify the most diagnostic variables and create a model to predict suitability decisions along the four scales based upon an optimized combination of the annotations entered

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by examiners for key variables and objective clarity and rarity data as measured by existing models. This model will ultimately be offered for use in reducing variability in suitability decisions within working laboratories. Preliminary results of the white box study phase of the project were presented here.

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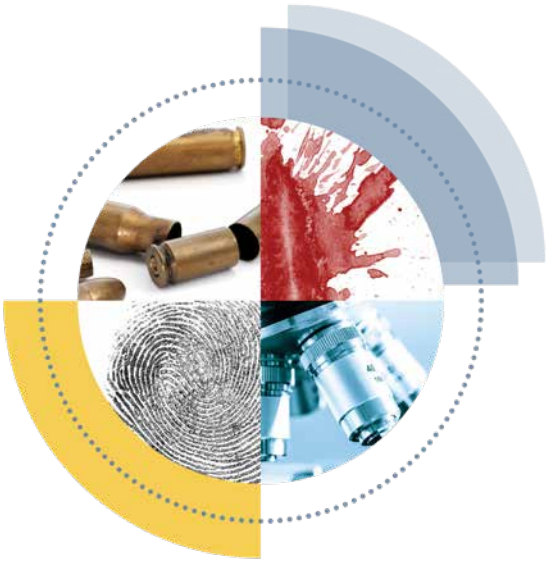
TRACE EVIDENCE BREAKOUT SESSIONS



Developments in Footwear Investigations

David Stoney, PhD

Stoney Forensic, Inc.

Particle combination analysis (using VSPs) is a new approach, highly significant for its potential to expand the number of cases to which trace evidence can meaningfully contribute and for its ability to include a quantitative statistical approach to data interpretation (Stoney & Stoney, 2014; Stoney, Bowen, & Stoney, 2015). Research has demonstrated that this approach has exceptional promise to expand the number of cases where trace evidence can be used and to provide quantitative measures of evidential value. The laboratory analyses are highly efficient, utilizing existing crime laboratory personnel and equipment.

The current state of development of Particle Combination Analysis was briefly reviewed: what has been demonstrated, what has been suggested, and what remains to be done. Prior research, employing reasonable choices of analytical and statistical parameters, has (1) demonstrated the presence of highly discriminating VSP profiles on the surfaces of common items of physical evidence, (2) characterized VSP combinations using analytical instrumentation and expertise commonly available in forensic laboratories, (3) developed statistically rigorous measurements of correspondence between VSP profiles, and (4) produced objective measures for the resulting probative value (Stoney, Bowen, & Stoney, 2015; Stoney, Neumann, Mooney, Wyatt, & Stoney, 2015; Stoney & Stoney, 2017).

The reasonable choices of analytical and statistical parameters employed in prior research were sufficient to demonstrate feasibility and potential. Systematic development and validation of these methods requires that the analytical and statistical parameters be more critically examined and that the key factors influencing the performance of the methods be identified.

The optimization of a VSP analysis protocol requires that factors influencing the reliability, costs, and selectivity be identified. Separating factors (a quantity or quality that does have an influence upon the system) from variables (a quantity or quality that might have an influence upon the system), requires a screening stage of experimental design. The result will be identification of a few important, controlling factors that must be addressed in order to meaningfully optimize the protocol. It will also provide information, such as the variability and magnitude of effects that will be needed for the next stage of process improvement.

Determination of the key factors and the magnitude of their effects will result in a significantly improved capability. Analytical and computational parameters, previously selected as reasonable choices, can be revised and replaced, with a combined effect that will have a material impact. Secondly, these results will provide necessary input to experimental designs that will permit systematic improvement and optimization. Identification of key factors will enable these critical steps and further the transition of particle combination analysis to practice. Thirdly, and most importantly, the results will contribute directly to the fundamental advancement of a new quantitative and broadly applicable approach to trace evidence. Well-documented factors and effects for one VSP analysis protocol will allow parallel, collaborative assessments of alternative options for high-efficiency analysis of VSP (such as micro Raman methods,

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micro X-ray fluorescence [XRF], genetic analysis, or alternative scanning electron microscopy/energy dispersive spectroscopy [SEM/EDS] protocols).

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Particle Combination Analysis in Footwear Investigations

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The separation of particle signals arising from different sources is one of the enabling operations for particle combination analysis (PCA) (Stoney & Stoney, 2014). Although it is well recognized that criminals track dust to and from every crime scene, dust particles on a suspect's shoes are very seldom used as evidence linking the accused to the crime. The major obstacle preventing the use of this type of evidence is that the shoes have mixtures of particles arising from activity before, during, and after the crime itself (Morgan et al., 2009). Methods separating the evidentiary particle "signal" from background noise would enable a powerful new and widely applicable forensic capability. This capability would augment traditional footwear pattern evidence with objective quantitative associations, addressing one of the specific issues raised in the 2009 National Academy of Science (NAS) report. To help pursue this possibility, methods are being developed and tested that will lead to better understanding of the loss and replacement of very small particles (VSPs) on the contact surfaces of footwear.

Prior work established that a 250 m walk (approximately 175 steps per shoe) removes and replaces particles on the outermost contact surfaces of footwear (Stoney, Bowen, & Stoney, 2016). It is important to achieve a better understanding about how quickly this replacement occurs. This understanding will (1) help interpret the significance of the traces found on the contact surfaces (representing the most recent environment(s) to which the footwear was exposed—how recent?) and (2) provide a foundation for the differential analysis of these traces and those found on other areas of the footwear.

Two distinctly different and commonly encountered types of shoe soles were used in this study: athletic shoes (with flexible rubber soles) and work boots (with hard rubber soles). Three well-characterized environmental sites with characteristic VSP profiles (distinguishable by defined qualitative and quantitative particle characteristics) were used for footwear exposures under dry, dusty conditions.

Thirty-six pairs of shoes (18 pairs of each type) were exposed to a "loading site" by walking distances of 175 steps/shoe: six pairs (12 shoes) of each type in each of the test site environments. For each set of 12, two shoes (one pair) were set aside as a control (zero steps in the second environment). Each of the remaining five pairs of shoes were exposed for a different number of steps to second of the three environmental sites: 5, 10, 25, 50, and 100 steps/shoe.

VSPs were recovered from the contact surfaces of all shoes by swabbing, analyzed by polarized light microscopy and interpreted using a (1) chi-square measure of distance and (2) Latent Dirichlet Allocation model developed by two of the authors at South Dakota State University (M.A. and C.N.).

Substantial loss and replacement of VSP occurs on contact surfaces of footwear in as little as five steps/shoe. By 25 steps/shoe the replacement is substantially complete. Knowledge of the rapid loss and replacement on contact surfaces provides a basis to explore differential analysis of (1) VSP signals from the contact areas of footwear and (2) those from more recessed areas of the footwear sole.

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Location Detection and Characterization in Mixtures of Dust Particles

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Dust particles recovered from the soles of shoes may allude to the locations recently visited by an individual. In particular, they may indicate the presence of an individual at a particular location of interest, for example, the scene of a crime.

A dust profile at any given location can be described by the respective proportions of the different particle types that are present at that location. The dust mixture recovered from a shoe, then, corresponds to a mixture of the dust profiles of the different locations that have been visited by the individual wearing the shoes. During this project, we have developed a statistical model that resolves mixtures of dust profiles and answers two foundational questions:

1. Given samples of dust from N known locations, and a mixture of dust (consisting exclusively of some or all of the N known locations) recovered from under a pair of shoes, what proportion of the dust mixture originates from each of the N locations?
2. Given a mixture of dust from N+M locations recovered from under a pair of shoes, but samples of dust from only N known locations, what are the dust profiles of the M unknown locations, and in what proportions are these M unknown locations present in the dust mixture?

Our model is based on latent Dirichlet allocation, which is a generative probabilistic model developed for natural language processing. For this project, we modify the original model to account for multiple sources where dust can be generated and multiple locations where dust sampled might be recovered. We also introduce constraints to facilitate the training of the model. Parameters are estimated using variational Bayesian inference.

The scope of our presentation is to familiarize the audience with an objective, interpretative approach that may considerably change the way small particles are used for forensic purposes. The first objective of our presentation is to convey the gist of our model by means of a simple acyclic graph, which will aid in portraying the generative process of dust mixtures. The use of this acyclic graph will allow the audience to gain insight into the generative process of dust samples as well as the underlying relationships that exist between sources that generate dust, dust profiles at given locations, and the respective proportions of these profiles in dust mixtures, without having to delve into complex mathematics.

Following this brief overview of the concepts behind the model, the second objective of our presentation is to discuss the performance and robustness of the model under different scenarios using simulated data. The first round of simulations investigates the ability of the model to accurately determine the true mixing proportions of N known dust locations in a dust mixture (a) when the dust profiles at these locations are (dis)similar from each other and (b) for different levels of dilution (e.g., for N=2, our dilution levels were 1:1, 1:2, 1:3, 1:4, and 1:9). The second round of simulations is similar in execution but this time focuses on mixtures composed of dust from a known element (i.e., dust profiles from a varying number of known locations) and an unknown

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element (i.e., dust profiles from a varying number of unknown locations). This set of simulations serves to describe the extent to which the model is able to extract the profile(s) and relative contribution(s) of the unknown location(s) to a mixture of dust under the same conditions studied during the first round of simulations (i.e., mixtures of multiple similar profiles in varying proportions, mixtures of multiple distinct profiles in varying proportions). Overall, our results show that it is possible to resolve mixtures of dust profiles, hence removing one of the main limitations of the use of particles in forensic science. Furthermore, our model can be used to statistically associate mixture elements with given locations of interest. The implication of our results is that the examination of dust particles has great potential as a forensic tool in the near future.

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Elemental Analysis of Adhesive Tapes as Forensic Evidence by LA-ICP-MS and LIBS

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Pressure-sensitive adhesive tapes are often submitted as evidence, as they may be used for packaging drugs, in the manufacture of improvised explosive devices to immobilize victims in assault and rape cases, among other criminal activities. The use of laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) and laser induced breakdown spectroscopy (LIBS) has been shown to improve the discrimination and characterization capabilities for tape analysis over other, more conventional methods by detecting over 15 elements in the analysis of electrical tapes. The method for the analysis and comparison of tapes by LIBS was developed and reported here for the first time. A comparison of the analytical figures of merit for the analysis of electrical and packaging tapes using both LA-ICP-MS and LIBS is also reported.

Two inter-laboratory trials were completed including several active forensic laboratories and academic researchers. The first inter-laboratory test consisted of the analysis of three known electrical tapes (Ks) and three questioned electrical tapes (Qs) by conventional methods: physical characterization and microscopy, scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS), Fourier transform infrared spectroscopy (FTIR) and pyrolysis–gas chromatography–mass spectrometry (Py-GC-MS), and LIBS and LA-ICP-MS. The participants were asked to compare each K to all the Qs. The samples selected consisted of two 3M Scotch and a General Electrical tape.

A second inter-laboratory test was designed comprising only the elemental analysis methods: SEM/EDS, LIBS, X-ray Flourescense (XRF), and LA-ICP-MS. The samples sent for the second inter-laboratory test consisted of one K and three Qs. The three electrical tape samples were Scotch 3M, not differentiated by organic/molecular spectroscopy or physical analysis. The main conclusions from both inter-laboratory trials were as follows:

- The Scotch 3M tapes were not always differentiated when using microscopy, FTIR, and SEM/EDS. These techniques were not always suitable to detect slight differences in the chemical composition of these 3M tapes.
- LA-ICP-MS and LIBS correctly associated each K to its respective duplicate sample within the Qs as well as found major differences between the different 3M tapes and increased the element menu by more than 10 elements for LIBS and 15 elements for LA-ICP-MS.
- The reporting language varies greatly between laboratories for the physical description(s) of the samples and for the final reporting and interpretation of the findings.
- Similarly, the methods of analysis for LA-ICP-MS and LIBS were developed and optimized for packaging tapes. A sample set consisting of eight packaging tapes originating from Asia were analyzed by both methods, and the performance of LIBS was assessed by comparing the results to the well-established LA-ICP-MS. The use of these laser-based methods allowed for the detection of up to 7 elements by LIBS, and 11 elements by LA-ICP-MS.

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In addition, LIBS proved especially useful in detecting elements that were problematic by LA-ICP-MS such as lithium and potassium. Multivariate analysis of the data was used to visualize chemical similarities and/or differences obtained by each technique.

A "Total Light Area" normalization was used, as this strategy provided very good analytical figures of merit for the comparison of packaging tapes for the selected elements. The best-performing comparison criteria for the packaging tapes by LIBS were found to be spectral overlay and comparing the means +/-5s. These results show that LIBS is a viable alternative to the already established LA-ICP-MS for forensic analyses and comparisons of tape evidence.

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Untangling the Relationship Between Hair Microstructure and Ancestry

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Patterns of variation in morphology and microstructure are frequently applied in forensic contexts to resolve or support questions of ancestry and personal identification. Human hair varies considerably in form and color within an individual and among groups. We tested the reliability and limitations of traits frequently applied in forensic hair examinations by measuring the diversity in human hair form, its size and shape, and the density and distribution of pigment granules (melanosomes) within hair. Differences in hair form and cuticle thickness are apparent between broadly defined geographic ancestry groups, but these categories do not necessarily reflect our modern admixed world.

This presentation covered a portion of my dissertation research as it relates to hair traits and their association to ancestry. I focused on research resulting from two collections of human hair. The first is the historic Trotter hair collection, used in some of the foundational research on human variation. The second is a recent study at Pennsylvania State University, where we sampled human hairs along with DNA for genotyping to estimate genetic ancestry. The hair samples from these collections have been used to study the relationship between hair form and microstructure with ancestry.

Part 1: Human scalp hair is highly visible and can exhibit pronounced variability in color, degree of curl, cross-sectional shape, diameter, and length. Variation exists within and between populations. In recent years, the lack of quantitative studies focused on hair morphology has been cited as a contributing factor for the imprecision, and lack of reliability, noted in forensic reports (President's Council of Advisors on Science and Technology [PCAST] and National Academy of Science [NAS] reports). These critiques failed to account, however, for studies of morphological variation in hair by race undertaken by early 20th-century anthropologists.

Method. Using oil immersion microscopy and ImageJ, we measured hair shape, size, and pigmentation patterns within and among populations using hair samples from the Trotter Collection at the Smithsonian National Museum of Natural History. Mildred Trotter was an anatomist and physical anthropologist whose studies of hair form variation, growth, somatic distribution, racial characteristics, and sex differences during the early part of the 20th century make up some of the foundational research that led to microscopical hair analysis as conducted in forensic laboratories today.

Result. Analyses of hair dimensions and the number and distribution of pigment particles within a hair cross section revealed variability within groups and demonstrated that hair traits are not easily separable into distinct categories by ancestry.

Discussion. These findings offer support for eliminating the use of the outdated three-category racial typologies. We observed general trait patterns that may be useful for future research and point to the need for additional research on the effects of admixture to better assess ancestry traits in human hair.

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Part 2: The three-layer structure of hair and differences in individuals, groups, and between groups has been the focus of much research.

Method. Using transmission electron microscopy (TEM), we investigated the degree of cuticle variability within individual hairs, within an ancestry group, and between groups. Forensic hair analysis incorporates assessments of thin or thick cuticle dimensions generally associated with ancestry, but these broad trends have not been rigorously investigated. We tested these assumptions using hair samples from participants of known European, East Asian, and African genetic ancestry.

Result. Measurable differences were found in cuticle thickness and in the number of cuticle layers among all three groups.

Discussion. Hairs associated with African ancestry tend to have thinner cuticles with fewer layers making up the cuticle, while hairs from people of European and East Asian ancestry tend to have thicker cuticles made up of more layers. Variation between European and East Asian samples showed some dissimilarity in cuticle thickness and in the number of layers, but these distinctions were not statistically significant. Testing European and East Asian hairs against African hairs showed statistically significant differences in the cuticle thickness and number of layers.

Part 3: The racial terminology used by forensic scientists to classify hairs is outdated and no longer scientifically supported. We conducted a blind interlaboratory study and reviewed proficiency test report language to examine how forensic analysts are currently analyzing and describing hair. Combining trait descriptions with ancestry terminology will be presented as a way forward for hair analyses. Ancestry assessments from the hairs analyzed in the interlaboratory study and their known levels of genetic ancestry will be used to demonstrate the extent that hair examiners can indicate admixed ancestry.

Conclusion: Using both light microscopy and TEM, we tested hair traits used by forensic analysts when classifying ancestry based on hair form and patterning of microscopic characteristics. From these tests, we found that there are differences in hair shape and cuticle dimensions between broadly defined ancestral populations. We also found significant within-person variability and within-group variation, so some traits should be used with caution when attempting to rely on measurements to classify unknown hairs to a particular ancestry group. How to appropriately qualify conclusions and report language was discussed.

This research has been funded by a combined grant from National Science Foundation (NSF)-National Institute of Justice (NIJ) (award 1453571), "Variation in Human Hair Morphology within and among Human Populations."

An Assessment of Head Hair Comparison via Protein Profiling

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Federal Bureau of Investigation

Recently, scientists from Lawrence Livermore National Laboratory's Forensic Science Center and other collaborators developed a hair shaft protein–based method for human identification. This method exploits genetic information preserved in hair proteins in the form of single amino acid polymorphisms (SAPs). As such, the SAP profiling technique has the potential to play a critical role in our ability to complement forensic microscopic hair comparison.

The goal of our research was to conduct a preliminary assessment of the efficacy and reliability of SAP profiling for its potential use in forensic casework. We conducted two preliminary studies: (1) determining the adequate hair shaft length required for analysis via SAP profiling using a protein extraction method developed in our laboratory and (2) evaluating the accuracy of current methods for identifying SAPs.

On the first objective, a single hair from a single donor was serially sectioned into five hair lengths, from 2 to 0.12 cm. Our study identified 299 and 130 proteins in 2 and 0.12 cm of hair shaft, respectively. Of these proteins, about 85 percent were nonkeratins and 3 percent were hair keratins. Hair keratins were mostly resistant to a decrease in hair length. Thus, we determined hair segments of 2 to 0.12 cm can provide enough information for proteomic analysis.

The second objective of this study was to determine the best method to accurately identify SAPs from mass spectral data. Typical mass spectral analysis software does not have the ability to identify peptides that may vary from public protein reference sequence databases (i.e., genetically variant peptides or GVPs). Two alternative options to identify GVPs and SAPs are to (1) use an open software program called Global Proteome Machine (GPM) or (2) build a custom database of human protein sequences that mass spectral analysis software can search against.

For this pilot study, we compiled SAP profiles of two keratin proteins (KRT86 and KRT35) derived from three human subjects using both methods. The GPM method created profiles that contained on average about twice as many SAPs than our custom database. Sequencing of nuclear DNA obtained from the three donors, which helps determine false positive and false negative rates, were presented. Based on our preliminary data, it is clear the main concern for the SAP profiling technique is no longer whether we can extract proteins from small hair lengths (e.g., 0.12cm) but is now identifying a set of core SAPs that could be used for human hair shaft comparison.

Instrumental Validation of a Scanning Electron Microscope with Energy Dispersive X-Ray Spectroscopy

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Boston Police Department Crime Laboratory

The push for ISO 17025 accreditation of all forensic science laboratories has been ongoing, and one of the requirements of the accreditation process is the validation of methods, specifically section 5.4.5 in the ISO 17025 document. After purchasing and installing our JEOL IT300LV SEM with Oxford X-MaxN EDS using the AZtec software, the task of validating the instrument for use with trace evidence samples was the next step. In the attempts to cover ISO 17025 validation requirements, our accrediting body's supplemental requirements, and our own laboratory's validation requirements, a plan was drafted, edited, and eventually carried out. The Boston Police Crime Laboratory validated the scanning electron microscope with energy dispersive X-ray spectroscopy (SEM/EDS) to determine the reliability, reproducibility, and sensitivity of the instrument. The validation included verifying the magnification and measurement tools using a copper grid, testing the resolution of the EDS with a known Manganese (Mn) standard, determining the X-ray range using a known Molybdenum (Mo) standard, determining the lower eV limit using a known Boron (B) standard, testing the beam energy range by examining the Bremsstrahlung curve, monitoring the consistency of the probe current with a pinhole aperture and a current meter, and analyzing the reproducibility of the spectra using different trace evidence samples. After performing several repetitions on all these steps, a validation report was drafted and the SEM/EDS procedure for trace evidence casework samples was finalized. Gunshot primer residue is a new category of testing for the Boston Police Crime Laboratory, therefore, the validation of the SEM/EDS for analyzing gunshot primer residues has started, and this validation plan has been revisited and edited as new information is obtained from the forensic science community. Discussing the complex validation process of the SEM/EDS for trace evidence sample analysis, including gunshot primer residues, may assist other laboratories with their validation and avoid duplicating efforts. The information gained from can be used in any laboratory setting to validate an SEM/EDS for use with trace evidence samples, including glass, tape, paint, general unknowns, and gunshot primer residues.

Special thanks are to be given to Matney Wyatt (US Army Criminal Investigation Laboratory), David Edwards et al. (JEOL), and Richard McLaughlin et al. (Oxford), and other forensic scientists.

Attenuated Total Reflection Infrared Microscopy and Charpy Impact Tester for Analysis of Automotive Paint Smears

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Oklahoma State University

Paint smears, which represent a type of automotive paint sample found at a crime scene, have proven problematic to forensic automotive paint examiners as there are no reference materials available in paint databases to generate hit-lists of potential suspect vehicles. A procedure based on a Charpy impact tester has been developed to generate smears (e.g., abraded or deformed clear coats, clear coat and color coat layers mixed together, or clear coat, color coat, primer, and e-coat layers mixed together) due to paint transfer from an automotive substrate to any surface of interest under conditions simulating those of a real collision. As revealed by an attenuated total reflection (ATR)–infrared (IR) microscope and multivariate curve resolution, there is separation of the automotive paint layers in some regions of the line map but not in other regions. In contrast, a paint smear appears intact in all regions of a line map using transmission IR microscopy. The unmixing of the layers is evident only with ATR-IR microscopy because of its superior spatial (x, y, and z) resolution. Because smeared paint in all likelihood undergoes melting due to the heat generated by the impact, a separation phenomenon may occur during fluid flow due to differences in viscosities and/or affinities for the substrate. This result indicates that paint smear standards can be developed for proficiency testing using the approach described here. The Charpy technique can also simulate an automobile collision with controllable collision speed and direction as well as momentum/energy transfer. This suggests that investigative lead information about the speed and momentum of a vehicle involved in a collision as well as the make, line, and model of the vehicle can potentially be obtained from a paint smear using ATR-IR microscopy to analyze the smear and a Charpy impact tester to simulate the smear.

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Development of Infrared Library Search Prefilters for Automotive Clear Coats from Simulated ATR Spectra

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A previously published study featuring an attenuated total reflection (ATR) simulation algorithm (Lavine, Fasasi, Mirjankar, Nishikida, & Campbell, 2014) that mitigated distortions in ATR spectra was further investigated using pattern recognition techniques to evaluate its efficacy in enhancing searching of infrared (IR) transmission libraries. In the present study, search prefilters were developed from simulated ATR spectra to identify the assembly plant of a vehicle from ATR spectra of the clear coat layer. Four-hundred-fifty-six IR transmission spectra from the Paint Data Query (PDQ) database that spanned 22 General Motors assembly plants serving as a training set cohort were transformed into ATR spectra by the simulation algorithm. These search prefilters were formulated using the fingerprint region (1500 cm-1 to 500 cm-1). Both the simulated ATR spectra (training set) and the experimental ATR spectra (validation set) were preprocessed for pattern recognition analysis using the discrete wavelet transform, which increased the signal to noise of the ATR spectra by concentrating the signal in specific wavelet coefficients. ATR spectra of 14 clear coat samples (validation set) measured with a Nicolet iS50 Fourier Transform Infrared Spectroscopy (FTIR) spectrometer were correctly classified in the assembly plant(s) of the automotive vehicle from which the paint sample originated using search prefilters developed from 456 simulated ATR spectra. The ATR simulation algorithm successfully facilitated spectral library matching of ATR spectra against IR transmission spectra of automotive clear coats in the PDQ database.

Emmons (2007) and coworkers previously reported that frequency shifts for some vibrational modes are observed in IR spectra of polymers measured in a high-pressure transmission diamond anvil cell (DAC). Emmons attributed these observed frequency shifts to the removal of void spaces in the polymer which occurred during the compression of the sample by the DAC. Although the advanced ATR correction module of OMNICTM cannot correct for this type of spectral shift when converting ATR spectra to IR transmission spectra, the ATR simulation algorithm can correct for these shifts because the simulation algorithm utilizes both the IR transmission spectra of automotive clear coats from the PDQ library and the corresponding ATR spectra of the same paint samples to develop estimates of the incident angle relative to normal for the internal reflection element, the refractive index of the clear coat layer, and the thickness of the paint sample after compression by the DAC. As there are currently no commercial vendors that distribute high-pressure DAC with sufficient energy throughput for automotive paint analysis, the ATR simulation algorithm described here will allow forensic laboratories to continue to utilize the spectral database of PDQ for IR library matching.

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Further Persistence Studies of PDMS Condom Lubricants

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Analysis of intimate swabs from alleged sexual assaults for the presence of condom lubricants is becoming a routine request for many trace forensic laboratories. The increasing public awareness of the high evidential value of DNA has seen an increase in the use of condoms by sexual offenders.

Persistence studies of such lubricants are vital to supporting the interpretation of forensic samples analyzed for the presence of condom lubricants.

Most condoms in New Zealand are lubricated with polydimethylsiloxane (PDMS), with fewer containing water-soluble lubricants such as polyethylene glycol (PEG). Intimate swabs are routinely analyzed for the presence of PDMS by extracting the swabs with hexane and analyzing these extracts using pyrolysis-gas chromatography-mass spectrometry (Py-GC-MS).

Previous research has focused on the persistence of PDMS in the vagina. This presentation will include the results of research focused on investigating the persistence of PDMS on the penis, in the mouth, and on skin. This research also investigated whether PDMS is present on tampon products available on the New Zealand market and whether PDMS can be detected on intimate swabs that have previously undergone DNA extraction.

Methods

Penis. Volunteers applied a condom to their penises for a few minutes. After removal of the condom they self-swabbed their penises at specified time intervals and recorded their activities during this time.

Mouth. A blank swab was taken from the mouth of each volunteer by asking the volunteer to rub a cotton swab against the inside of the cheeks and gums. A condom was then placed on a carrot, and the volunteer moved this around in his or her mouth for a minute to simulate oral sex. The volunteer then self-swabbed the inside of the cheeks and gums after specified time intervals. Some volunteers were asked to abstain from eating and drinking during these time intervals.

Skin. Volunteers' forearms were marked using a marker into areas of approximately the same size. Prior to the transfer of PDMS, a control sample was taken by swabbing the inner forearm with a wet swab (preliminary trials determined that wet swabbing recovered more PDMS from skin than dry swabbing). A condom was then placed on a carrot or cucumber and firmly swiped against volunteers' inner forearms. One area of the forearm was swabbed immediately for the initial trials. Volunteers then self-swabbed each marked area of their inner forearms after specified time intervals. The volunteers were asked not to use any personal care products that contained PDMS or other silicone-containing compounds during the time intervals.

Tampons. A range of tampon products available on the New Zealand market was donated by colleagues. One tampon per product was analyzed by extracting four strips of the outer layer and cotton from below the surface. Any applicators present in these products were also analyzed by swabbing the applicator and extracting these swabs.

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Swabs for DNA extraction. Two sets of cotton tip swabs were loaded with a known volume of a PDMS solution. One set of swabs was retained as the control swabs, and the second set was extracted for DNA, using standard DNA methods. The swab heads remaining after DNA extractions were extracted and analyzed. The supernatant from the DNA extraction process was also analyzed.

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Subpopulation of Fibres and Their Importance to Forensic Science

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A fibre population study with 2,387 fibres was conducted at London South Bank University to gauge the frequency with which they appeared (to be used in criminal investigations). London South Bank University classroom seats were collected using tape and analyzed with different techniques. This university was chosen because it has a representative sample of seats with several different fibres, given the mixed origin of students.

Each fibre from the population study was analyzed individually and classified accordingly (e.g., color, characteristics, natural or synthetic, presence of medulla, presence of delustrant). Fibres were analyzed using low-power microscope, high-power microscope, comparison microscope (using different light sources), Fourier transform infrared spectroscopy (FTIR) and microspectrophotometry (MSP). From the population study, it was concluded that the majority of fibres were natural (82 percent), most of them blue-colored cotton. Other characteristics such as presence of delustrant on synthetic fibres were also observed in some fibres. The most common combination of fibres was blue-black cotton (497 fibres), and the least common were acetate fibres other than blue-black. Cottons were found in all the colors apart from black-black. Comparing the front of the seats with the back of the seats, it was found that cotton fibres were much more prevalent in the front of the seats and that synthetic fibres were less discrepant (a similar number of synthetic fibres was found in front of the seats and in the back of the seats). After classification of all fibres, a fibre population was found and respective statistics were outlined. Some types of fibres, namely cottons, were very common in this population study. Subpopulation studies are important because they can increase the certainty of two fibres being from a similar garment. In comparing a pink cotton fibre with criminal evidence, it would be known that pink fibres are not very common and therefore, in the presence of a match, the probability of the two fibres being from the same garment would be much higher. But in some cases, the fibre could be very common (e.g., blue cotton fibres), and consequently subpopulations might help to increase or decrease the strength of a piece of evidence. Using this fibre population, I analyzed subpopulations of red-pink fibres. Despite being more infrequent than blue cotton fibres, red-pink fibres were interestingly found often in this study. So there is clear interest in studying this type of fibre further. This study analyzed 188 red-pink cotton fibres. Using MSP, spectra to all these fibres were obtained and compared. Twenty-one subpopulations of red-pink cotton fibres were found with a range of 2 to 11 fibres in each. About 100 could not be included in any subpopulation study due to their specific spectrum, a point to be further discussed. The presentation includes a discussion of the findings of subpopulation studies, a perspective from Europe, particularly their importance in criminal investigations.

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Comparison of Intra-Roll Subclass Characteristics in Polymer Films

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Polymer films are commonly encountered as forensic evidence in a wide variety of criminal cases. Plastic bags can be utilized as weapons for the purpose of asphyxiation or suffocation, as wrappings to conceal victims' bodies or body parts, as a means of disposal of incriminating evidence, and as drug packaging.

Latent prints, DNA, foreign hairs, and fibers can all be present on or in plastic bags and can be valuable in connecting a suspect to a victim or a crime scene. Comparisons of polymer films can also be made to establish an association between a known and a questioned bag or to eliminate a known bag as being the source of a questioned bag.

The examination of polymer films includes chemical analysis of the components as well as comparison of multiple physical class characteristics such as length, width, color, film thickness, film layer structure, orientation of fold lines, seal marks, hem width, and perforation pattern. Levels of association between plastic bags range from the association of general class characteristics to the unique identification of individualizing characteristics, that is, a physical/fracture match formed between consecutively manufactured bags from the same roll. However, there are levels of association in between, which rely on the comparison of subclass characteristics. Subclass characteristics are unintentionally produced by surface features like die lines that result from the manufacturing process. Per the AFTE Glossary (version 6.101613, 2013), subclass characteristics are "features that may be produced during manufacture that are consistent among items fabricated by the same tool in the same approximate state of wear. These features are not determined prior to manufacture and are more restrictive than class characteristics."

The current study aims to assess intra-roll variation of subclass characteristics on polymer films. Multiple rolls of plastic bags of the same manufacturer and type will be purchased, if possible from multiple separate vendors. The extrusion patterns, heat seals, perforation patterns, and other manufactured features from each bag within a single roll will be examined to determine if the pattern shifts, repeats, and/or changes from the first bag to the last. It is hypothesized that intra-roll variation will be minimal since the striations in the extrusion patterns are largely formed by semi-permanent tool marks in the manufacturing die. These tool marks may change over time as new wear and damage accumulate on the die but should feasibly remain consistent within a single roll of bags. It is possible that the extrusion pattern will shift left or right within a roll depending on the specific manufacturing process. This research does not aim to be comprehensive in scope. Rather, the current study aims to demonstrate that subclass characteristics are consistent within a single roll of plastic bags. If the same subclass characteristic features are encountered in known and questioned polymer films during a casework comparison, there is potential for a stronger associative conclusion between the two items than would exist between two items sharing class characteristics alone. Further study of this topic will expand the sample size and will include additional manufacturers and types of polymer

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film. Future study also aims to address the inter-roll variation of subclass characteristics on polymer films.

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The Effect of Fingerprint Chemicals on the Chemical Analysis and Comparison of Duct and Cloth Tapes

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Pressure-sensitive adhesive (PSA) tapes are often submitted to crime laboratories as evidence associated with violent criminal activities. Adhesive tapes are not only collected for their exploitation as an evidence type in themselves but are also searched for other evidence such as DNA, fingermarks, fibers, and hairs. These collections often take precedence over analysis of the actual tape, and consequently these preliminary evidence collection techniques might influence the original tape composition, particularly with respect to the use of fingerprint chemicals.

Through casework, it has been observed that on some occasions where a tape sample from a scene or person has been treated with fingerprinting chemicals prior to submission for comparison to a known roll, minor but reproducible differences have been observed between the samples. While this could show that the tape pieces are from a different source, whether the presence of the chemical treatment may have been an influence must also be considered.

This research project examined the effect of different fingerprint chemicals and treatments on eight different PSA tapes, including those with and without scrim, their chemical analysis, and the comparison with the original untreated tape. The fingerprint chemicals used were cyanoacrylate fuming, rhodamine 6G staining, and black and white powder suspensions (Wet Wop™). The chemicals were applied on fresh prints as well as on 1-month old prints. The analytical techniques utilized for the tape examination included visual examination by the unaided eye, the macroscope, and a video spectral comparator (VSC6000). In addition, nondestructive instrumental analyses were adopted. These involved attenuated total reflectance (ATR) spectroscopy, RAMAN spectroscopy, and X-ray fluorescence (XRF) technology. The influence of the tested chemicals with the instrumental analyses on the tape samples showed that the powder suspensions had no observable impact on the tape. cyanoacrylate and rhodamine 6G staining on the other hand showed significant changes in the overall appearance of the Fourier transform infrared spectroscopy (FTIR) spectra compared with the original untreated tape. No impact was observed for the XRF analyses, and limited information was obtained using RAMAN. This initial work demonstrates that care should be taken when it is known that tape pieces have been chemically treated prior to submission for comparison against a known sample. The findings have provided useful data for forensic chemists at New South Wales Forensic and Analytical Science Service (NSW FASS), which may aid them in interpreting their casework findings.

Due to limited time and the limited scope of this initial study, further research has been proposed. This includes:

- Additional analyses by the chosen techniques such that a statistical evaluation of the data could be performed to visualize minor details and enhance the differences and similarities not observed by visual comparison of the spectra alone

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- Any chemical reaction between the tape itself and the fingerprint treatment
- Aging studies
- Environmental degradation studies
- Effect of untangling methods, particularly with respect to using chemicals, on the tape structure and composition

Dr. Bunford would like to thank Fabienne Brack for her hard work undertaking this study and writing her report, NSW FASS, and University of Technology, Sydney.

Integration of Pulp and Paper Fiber Microscopy into a Course on Forensic Paper Examination and Authentication of Historical Documents for Forensic Chemistry and Art Conservation

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Buffalo State College

This course concentrated on the examination of paper using special lighting methods, photography, and measurements using forensic instrumentation. The class looked at laboratory techniques for the recovery of writing from faded, burned, water-soaked, shredded, and obliterated documents using forensic and art conservation methods. Also covered were the dating of documents via fiber composition, pulping chemistry (as determined by micro-chemical tests and stains), manufacturing methods, and watermarks. The analysis of book binding and general typography as a means to establish provenance and authentication of historical manuscripts was conducted through the examination of historical cases. As time permitted and depending on student interest, simple calligraphy and illuminated manuscript techniques were practiced. This class was offered as a supplement to material introduced in FOR312, FOR 612, and FOR 497/598: Examination of Questioned Documents. An important, but specialized area of questioned documents involves detection of fraudulent alteration to documents and authentication of historical documents. The successful application of these skills requires knowledge of paper chemistry, paper manufacture, paper composition, and how these materials are organized, whether as a medical record or historical illuminated manuscript.

This class demonstrated the special skills needed to maximize recovery of information from documents under a variety of conditions. Students had the opportunity, through class exercises, to develop skills in the application of logical thinking and appropriate testing to accurately age a document and evaluate the significance of this information.

Sample research projects included:

- Researching an historical case involving documents of questioned authenticity and developing an approach to authenticate the document(s), developing an outline and flowchart of procedures and key diagnostic methods.
- Researching a method related to paper conservation and preparing a step-by-step guide, listing necessary materials and sufficient detail to carry out the procedure; discuss any limitations.
- Researching a method in conservation that might be applicable to forensic paper examination such as:
  - Conservation methods to flatten folded paper facilitating the application of Electrostatic Detection Apparatus (ESDA) and oblique lighting techniques for the visualization of indented writings in crumbled documents
  - Researching poly film encapsulation methods or other applicable methods for preservation of burned documents
  - Researching recovery methods for water-soluble paper
  - Researching the differences between art and business paper in terms of manufacture, use, grading, and forensic characterization.

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- Researching the identification and characterization of recycled paper—its manufacture, uses, and extent of production in the USA and overseas.
- Researching the identification and characterization of paper used in specific applications:
  - Tissue paper
  - Toilet paper
  - Parchment paper
  - Art paper
  - Water-soluble (dissolving) paper
  - Security paper
  - Other paper of your choice
- Researching an instrumental or chemical method for advanced characterization of paper such as elemental analysis; discuss the procedure, instrumentations, sample preparation, limitations, and general applications.
- You are setting up your own private papermaking and stationery business. Describe the type of materials and equipment you would need, prices, suppliers, type of paper products you intend to produce, and your proposed market, and create a brochure describing your product(s), equipment, and prices for prospective customers.
- You are setting up your own private calligraphy business for the production of illuminated letters as a central feature. Describe the type of materials and equipment you would need, prices, suppliers, type of products you intend to produce, and your proposed market, and create a brochure describing your product(s), equipment, and prices for prospective customers.
- You intend to forge an historical document of your choice. Describe the procurement of materials, aging steps, alterations, contents needed to establish provenance, and other incidentals needed to produce the document and avoid detection. The document and time period must be different from the student project piece.
- Other suitable projects related to forensic document examination, preservation, authentication, or review of historical case studies involving document authentication, with instructor approval.

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Transfer and Persistence of Glass Fragments: Experimental Studies Involving Vehicle and Container Glass

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West Virginia University

Experimental studies that estimate the distribution, transfer, and persistence of glass fragments are relevant for the interpretation of glass evidence. This study aims to add to that body of knowledge by evaluating transfer and persistence of vehicle glass and container glass under common scenarios.

Experiments were designed to simulate transfer of vehicle glass during kidnapping, vehicle crash, and murder scenarios. The transfer of glass to the person involved in the breaking event, to individuals nearby, between the person who broke the glass and another object, and to crime scene investigators attending the scene has been investigated.

A kidnapping scenario was devised involving the breaking of a driver's side car window with the victim in the driver's seat and three suspects positioned around the breaking window. Prior to the event, background glass was collected from those participating to provide a baseline control. Following the smashing of the window, the victim was bound and thrown into the trunk of the suspects' vehicle, and then the suspects drove away. After the scenario concluded, evidence was collected from the victim, the suspects, the exterior of the victim's car, and the interior of both the suspects' and victim's vehicles.

A vehicle crash scenario was conducted in collaboration with the Insurance Institute of Highway Safety for lateral and frontal crashes. The inside of the vehicle was sampled before and after the crash. Recovery of glass from the dummy passenger's and driver's clothing was completed after first responders attended the scene.

A murder event, with container glass as the murder weapon, was conducted inside one of West Virginia University's crime scene houses. Containers (wine and beer bottles) were broken against the victim with constant applied force. The clothing of the person who broke the bottles was collected afterwards, after the person performed some controlled activities such as walking, running, and/or driving. Secondary transfer to the vehicle driven by the suspect was also investigated.

Each experiment was repeated three times to evaluate the variability of fragment distribution. The glass pieces gathered were then sorted by size and documented. The immediate area around the impact sites were divided into quadrants, and heat maps representing the fragment quantities distribution, by fragment size, were created to evaluate the backward fragmentation patterns. Hand picking, vacuuming, and taping was used for the collection of glass at the scene, while at the laboratory, visual examination with microscope and light sources, taping, picking, scraping, and/or vacuuming were used for the recovery of glass. Examination and comparison of glass was conducted at the laboratory using refractive index and elemental analysis.

The transfer and persistence study provided important information that can be used for interpretation of glass fragments involving breaking of car side windows, windshields, and containers: (a) secondary transfer was observed

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on the suits worn by the crime scene recovery team and from the suspects to the vehicle's seats; (b) the majority of glass greater than 1 mm was lost from activity and secondary transfer; (c) the majority of the backward fragmentation produced fragments smaller than 1 mm; (d) the distance the fragments were ejected varied with the applied force, thickness of the glass, and shape/size of the glass; and (e) the majority of the vehicle's forward fragmentation was distributed between the front seats, with similar amounts of glass recovered from the driver and front-passenger seats in cases of lateral breaking impacts.

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Swab Touch Spray Mass Spectrometry for Rapid Analysis of Organic Gunshot Residue from Human Hand and Various Surfaces Using Commercial and Fieldable Mass Spectrometry Systems

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Purdue University

Forensic investigation into the possibility of a suspect discharging a firearm in recent years has expanded from elemental inorganic gunshot residue analyses to molecular organic gunshot residue (OGSR) analyses. Protocols have been developed for the collection and analysis of OGSR which focus heavily on the stabilizers present in many ammunition types such as methyl centralite (MC) (1,3-dimethyl-1,3-diphenylurea) and ethyl centralite (EC) (1,3-diethyl-1,3-diphenylurea). These two compounds were selected from the expansive list of OGSRs because they are not commonly used in any other application and would therefore be among the most discriminatory compounds for determining if a person has potentially discharged a firearm. The complementary nature of OGSR analysis adds a level of confirmation to the typical inorganic analysis that is traditionally performed. OGSR has been shown to be detectable on skin hours after discharging a firearm; however, there is degradation over time and improved in situ analysis would greatly benefit the forensic community.

Currently OGSR analysis has been accomplished by a number of analytical techniques, many of which require lengthy chromatography or extraction techniques. Forensic staples like gas chromatography and ultra-high-performance liquid chromatography have demonstrated their capabilities of identifying and determining the presence of OGSR. While these methods are reliable analytical techniques, they suffer from lengthy analysis times and are not amenable to in situ analysis. Similarly, the standard sampling methods for OGSR are various forms of swabs and stubs. In order for these chromatographic methods to be utilized, an extraction technique, such as a solid phase microextraction, must be performed. Where swabs and stubs are convenient methodologies for sampling, when combined with extraction techniques, the number of experimental and sample preparation steps increases, amplifying analysis time and extending the room for operator error and sources of contamination.

Presented here is an ambient ionization method that requires no sample preparation, offers real-time analysis, and can be paired with a portable ion trap mass spectrometer for in situ analysis. Swab touch spray utilizes a rayon-tipped swab to collect the analytes of interest by swabbing the dry swab over the area of interest (i.e., the hands of a suspected shooter, or an article of clothing of the suspected shooter). The swab is constructed with an aluminum handle which allows a high voltage lead to be connected directly to the swab to promote ionization when a solvent is applied. The aluminum handle is pertinent to swab touch spray because this is how the high voltage is applied; other handles like wood or plastic are nonconductive. This talk will demonstrate the ease of swab touch spray ionization, its forensic feasibility for OGSR, and its ability to be coupled to a portable mass spectrometer for in situ analysis.

All spectra were recorded in positive ion mode using a Thermo LTQ Orbitrap XL Hybrid Ion Trap-Orbitrap mass spectrometer (San Jose, CA) or a home-built Mini 12 rectilinear ion trap (Purdue University, West Lafayette, IN). All

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mass spectrometry/mass spectrometry (MS/MS) product ion scan mass spectra were generated through collision-induced dissociation (CID). Each swab was individually packaged with a tamper-proof label, removed from packing only to swab, and then returned to the casing. Each surface (bare hands, gloved surfaces, clothing, and spent casings) were swabbed in a circular motion after discharging the firearm. Approximately 20 circular motion passes were performed over the area of interest, for example, the top side of the right hand between the thumb and the pointer finger. The swabs were positioned vertically (approximately 8 mm) above the inlet of the mass spectrometer. High-performance liquid chromatography (HPLC)–grade methanol was applied to the swab via pipette to ensure that the swab was completely wet and a continual flow of methanol spraying solvent was delivered to the swab at a varied flow rate to maintain a steady spray. A high voltage of 5.5 kV was applied to the aluminum handle, and the generation of a spray could be visually observed.

Four different 9 mm handguns, with four different ammunitions, were used in this study. Different firearms and ammunitions were selected to determine if this could be a universal method. To minimize the confounded variables of shooter, ammunition, and firearm, the casing of each expended ammunition was swabbed and analyzed for the presence of MC and EC.

Three ammunitions were found to contain MC and EC, and a single discharge of the firearm provided enough of both compounds to be detected by swab touch spray mass spectrometry. The lower limit of detection for both MC and EC was lower than 50 ng on the LTQ XL. The researchers checked the inside of the other ammunitions' spent rounds and detected both MC and EC in all three. MC and EC were not detected in the fourth ammunition. As the composition of the bullets are not public knowledge, the researchers also swabbed the inside of the spent casing to determine if the lack of detection of MC and EC was a result of the swab or the lack of the two compounds found in the ammunitions. There was no signal of MC or EC for the casing either, to which the researchers propose that there may not be any MC or EC in this ammunition, or the MC and EC is more limited in quantity, and the quantity transferred to the surface is below the limit of detection of the technique. The Mini 12 was also able to detect both MC and EC after the discharge of a single round of ammunition. Determining if a potential suspect discharged a firearm is a time-sensitive matter. The Mini 12, which has been shown to be capable of in situ analysis, has demonstrably provided law enforcement with an answer in a more rapid, simple sampling method. Swab touch spray has been shown to be an effective method for identifying OGSR from a variety of surfaces: hands, gloves, clothing, and spent shell casings. This ambient technique requires no sample preparation, no lengthy analysis times, and is capable of in-field analysis.

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Evaluation of Field-Portable GC-MS with SPME Sample Collection for Investigator Use at Fire Scenes

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Objective: There has been no significant advancement in on-scene forensic fire debris analysis in over a decade. The ability to identify an ignitable liquid accelerant at the fire scene would provide fire investigators useful data, increasing their efficiency and effectiveness. This research project was intended to establish if the identification of ignitable liquids could be achieved at the fire scene.

Introduction: This approach is of particular value today when many law enforcement forensic laboratories, due to staffing shortages, are dropping fire debris analysis as a provided service or are assigning such cases such low priority that they are not analyzed in a reasonable time. With no laboratory analysis, canine alerts (or human suspicions) cannot be presented as evidence of an incendiary fire in judicial proceedings. With laboratory-grade analysis performed at the scene, the fire investigator would be able to proceed with the investigation with the results already in hand while still at the scene.

Method: Initial testing demonstrated that the field-portable gas chromatography–mass spectrometry (GC-MS) with solid phase microextraction (SPME) fiber sampling technique can confirm the identity of ignitable liquid vapors at the fire scene consistent with ASTM fire debris analysis techniques.

Approach: A second series of tests conducted in room fire tests that were allowed to burn to full-room involvement demonstrated that accurate ignitable liquid vapor identification could be achieved even when the vapors were measured (using a state-of-the-art "sniffer" at part-per-billion concentrations) after real-world fires. These debris samples were sent to a certified laboratory to confirm the results from the field data. A limiting factor in the field application of GC-MS was determined when the data produced had to be analyzed by a qualified GC-MS specialist to confirm the identification of the ignitable liquid. The current test series is being conducted with the services of a certified fire investigator (CFI) who is also a trained hazardous material responder, with the assistance of a certified arson accelerant canine. This will evaluate the accuracy of the canine detector in concert with the field-portable GC-MS against certified forensic laboratory analysis of the fire debris recovered from full-room fires.

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Forensic Sampling and Analysis from a Single Substrate: Surface-Enhanced Raman Spectroscopy Followed by Paper Spray Mass Spectrometry

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Forensic science relies heavily on so-called "hyphenated techniques," such as gas chromatography-mass spectrometry (GC-MS) or liquid chromatography-mass spectrometry (LC-MS), because of their long history of providing reliable, reproducible, and validated information. While reliable, these hyphenated analytical techniques suffer from relatively long analysis times, and they are typically not amenable to in situ analysis. The standards set by ASTM International and Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG) recommendations follow these practices, which makes nonchromatographic approaches a challenge unless a more attractive capability is newly available. These standards state that mass spectrometry is a validated "Category A" technique, the highest category based on discriminating power, but that a secondary technique must be utilized, for example nuclear magnetic resonance (NMR) spectroscopy, Raman spectroscopy, any of a number of separation techniques, or even colorimetric tests.

Paper spray (PS) ionization is an ambient ionization method which makes use of a paper substrate cut to a sharp tip from which ions are generated with the application of a high voltage and solvent. This simple technique can be used for direct sampling of complex mixtures. PS ionization has proven useful in the analysis of a wide variety of samples including dried blood spots, drugs of abuse, chemical warfare agents, and bacteria. Recent advances in PS ionization include surface modifications for improved ionization or reactive applications. Although PS excels as a rapid, cost-effective, and easy-to-use method, forensic applications require a secondary technique for analyte confirmation. Another paper-based method that has been developed, not for mass spectrometry but rather for Raman spectroscopy, involves the use of paper surface Raman substrates. Raman spectroscopy has gained popularity in forensics because of the increased sensitivity achieved in SERS. A particular advantage of paper SERS (pSERS) substrates is the ease with which they can be created using inkjet printers. Fabrication of pSERS substrates is straightforward compared with the typical microfabrication of SERS substrates, and it minimizes the cost of fabrication. pSERS substrates have been used to detect drugs, fungicide, pesticides, and polymerase chain reaction (PCR) products. While pSERS substrates are commercially available and attractive for forensics, this method too requires a second instrumental technique for confirmation.

Recognizing the complementary nature of these two methods, we demonstrate here the utilization of a commercial pSERS substrate for Raman spectroscopy analysis followed by mass spectrometry. The amalgamation of the two techniques provides a simple and fast forensic methodology requiring minimal sample preparation. To test this, standard solutions were pipetted onto the pSERS substrate, or the paper substrate was used to swab a surface, and a Raman spectrum was recorded after drying. The pSERS substrate then was used as the paper substrate for PS mass spectrometry, and a spectrum was recorded for the same sample. The entire analysis time was a few minutes.

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With the SWGDRUG guidelines being explicit on the requirement of two different methods, five drugs of abuse were tested by the combined pSERS Raman/paper spray–mass spectrometry (PS-MS) method. The selection of drugs encompassed several relevant samples. The increased use of synthetic designer drugs worldwide was the reason why 4-methylethcathinone was selected. Hydromorphone and morphine were selected because they are isobars and the Raman spectra aid in distinguishing them. Finally, heroin and fentanyl were selected because they have caused an increase in substance abuse and overdoses, especially in young adults. Production of fentanyl is a low-cost operation, and it is typically used to cut heroin, which has caused numerous overdoses. Spectra for heroin and fentanyl in their pure form as well as a simulated street sample in which the heroin is cut with fentanyl in a 10 to 1 ratio were collected. All the drug samples had distinguishable characteristic Raman shifts, and even the mixture street sample could be identified. This method was also tested for explosive residues of 2,4,6-trinitrotoluene (TNT), cyclotrimethylenetrinitramine (RDX), cyclotetramethylene-tetranitramine (HMX), and chemical warfare agent simulants, such as diisopropyl methylphosphonate (DIMP), dimethyl methylphosphonate (DMMP), and dichlorvos.

The use of a pSERS substrate for both Raman and PS-MS allows rapid analyte identification and confirmation without sample preparation steps as well as the use of a single substrate for complementary spectroscopic measurements. Both Raman and PS-MS can be performed in the ambient environment, which makes the coupling of the two instrumental techniques so appealing. The decrease in analysis time as compared with the hyphenated chromatography techniques could help decrease forensic sample backlogs. The substrates are low cost and readily integrated into a forensic laboratory workflow. These substrates work for both SERS and PS-MS, and as a cost-saving method, a biopsy punch could be employed to create five pSERS substrates from one test strip. Additionally, because the substrates are inkjet printed, highly customizable patterning could be employed to fit the needs of the study. This study has shown the range of compound types to which this dual instrumental method is applicable. The ability to help distinguish isobaric compounds, confirm compounds that do not readily provide informative tandem mass spectra, and finally the ability to swab a surface and analyze the compounds all add to the strength of this technique. The study has not been extended to quantitation, but quantitation using added internal standards in PS-MS is detailed in the review cited while modest quantitative performance in SERS without standards is reported. While not shown in this presentation, PS has been performed in situ on a portable mass spectrometer, and commercial portable Raman spectrometers are available. The ability to potentially perform this technique in situ would add value to the combined methodology.

Identification of Organic and Inorganic Gunshot Residues by Electrochemical and Spectrochemical Methods

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West Virginia University

In 2016, the US faced over 100,000 gun-related deaths and injuries, including 385 mass shooting events. Forensic laboratories provide valuable support in these investigations, through the chemical identification of firearm discharge residues (FDR) to identify a potential shooter, determine firing distances, or differentiate between a potential homicide, suicide, or accidental shooting. The scientific validity of this field relies on extensive research and standardization of the existing methods. Nonetheless, there are still some remaining challenges in this arena in terms of speed of analysis, preservation of evidence, accuracy, and interpretation of results. For instance, the detection of FDRs is influenced by many uncontrollable factors such as time and activities after the shooting as well as environmental contamination and interferences that could lead to errors. Thus, there is a critical need to improve the speed and reliability of these determinations. The combination of the detection of organic gunshot residue (OGSR) and inorganic gunshot residue (IGSR) is an attractive novel approach, particularly when sound chemometric data treatment is used for interpretation purposes.

The motivation of this study is to develop a more practical, simpler, faster, and superior approach to the identification of FDR, capable of simultaneous detection of IGSR and OGSR using laser-induced breakdown spectroscopy (LIBS) and electrochemical sensors. LIBS is a rapid chemical analysis technique that uses a pulsed laser for direct qualitative and quantitative analysis of materials with no sample preparation and minimal destruction. LIBS allows extremely fast measurements (usually 30–50 seconds for multiple-shot analysis) and simultaneous multi-element detection in the low parts per million (ppm) range. On the other hand, electrochemical sensors use electrical stimulation to induce redox reactions of the analyte at the surface of the electrode. Inorganic species (e.g., Pb, Cu, Zn, Sb) and organic species (e.g., nitroaromatics, nitroamines) are electroactive, allowing the detection of FDRs at low ppb levels. Electrochemical methods offer several advantages including rapid response, low cost, good sensitivity, good selectivity, and potential for miniaturization. Electrochemical and LIBS techniques are proposed as screening methods that are quicker, more selective, and more powerful than any current field-testing technique. These methods offer superior information by simultaneous detection of organic and inorganic components and identification of a larger number of elements used in modern ammunitions. Sampling methods were selected to remain compatible for subsequent confirmatory methods (scanning electron microscopy/energy dispersive spectroscopy [SEM/EDS]) in the same sample.

Optimization of the LIBS and electrochemical sensors was conducted using response surface Box Behnken experimental designs. Standards were prepared by spiking 50ng to 25 ug of Pb, Ba, Sb, Cu, Ti and Zn over a surface of approximately 1cm2 of SEM carbon adhesives. The rapid scanning of the laser beam across a single line of 100 um by 7 mm allowed the qualitative identification of 2 to 10 different emission lines per target element in less than 1 minute. Linearity better than 0.985 was obtained for Pb, Ba, and Sb

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with reproducibility between replicate measurements better than 11 percent relative standard deviation (RSD). Limits of detection for Ba (2 ± 0.2 ng), Pb (20 ± 3ng), and Sb (100 ± 12ng) demonstrate the method fit for purpose. Optimization of the electrochemical sensors demonstrated the feasibility of cyclic voltammetry (CV) and Square Wave Anodic Stripping Voltammetry (SWASV) for the rapid detection of inorganic and organic target compounds. Current research is focused on the use of disposable electrodes that permit laboratory and field- based testing. The detection of a mixture of 0.5ug (Pb, Sb) and 1.0ug (2,4-dinitrotoluene (DNT), 2-nitrodiphenylamine (DPA) was possible in 120 seconds. A 0.1 M acetate buffer (pH 4.5) was used as electrolyte to dissolve the mixture of metals and DNT. Seventy samples, 40 from shooters' hands and 30 from nonshooters' were collected as part of the validation study. Pistol (9mm and .22) and revolver (.357 Magnum) were fired at the ballistics laboratory under controlled environmental conditions, and at an open shooting range, using different types of leaded and lead-free ammunition. LIBS and electrochemical screening tests allowed the simultaneous detection of trace levels of OGSR and IGSR in just a few minutes (e.g., Pb, Ba, Sb, Cu, Al, Si, Ca, Sr, Ti, Zn, Sn, DPA, NG, and DNT). Less than 1 percent false positives and false negatives were observed after screening with both methods. The almost nondestructive nature of the approach would serve as a fast screening test prior to confirmation of IGSR by SEM/EDS. The application of such screening methods could reduce backlogs in forensic laboratories, reduce overall costs of analysis, and represent a promising alternative for onsite applications that require fast response and efficient decision making.

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Instrumental Analysis of Gunshot Residue (GSR)—Reconstruction of Crime Scenes

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Gunshot residue (GSR) particles from the surroundings of bullet holes have been characterized as a function of primer type and particle distribution. Scanning electron microscopy (SEM) images were used to verify size and shape of the GSR particles, and energy dispersive spectroscopy (EDS) to verify the elemental composition in a single particle. The same specimens are further subjected to time-of-flight secondary ion mass spectrometry (ToF-SIMS) and X-ray photon spectroscopy (XPS) analysis to identify the respective surface chemistry, molecular nature, and molecular mass of the GSR particles. Both inorganic and organic components of GSR in the elemental and combined form can be identified using SIMS. The study was helpful in distinguishing between real GSR particles derived from a particular firearm and those derived from environmental contamination for forensic investigations. Shooting distance, type of firearm, and nature of the incidents have been studied from characterization results.

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Evaluation of Error Rates in the Determination of Duct Tape Fracture Matches

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A piece of tape utilized in gaging a victim or assembling an improvised explosive device could become important evidence in forensic and intelligence investigations. In addition to potential DNA, fingerprint, or trace evidence left on the tape backing or adhesive, the tape itself could provide critical information in the reconstruction of an event. For instance, the identification of a fracture match between a piece recovered from a victim and a piece recovered from a suspect could demonstrate that the two pieces were once part of the same roll. Unlike some marks left on pattern evidence, tape fracture features are not "imprinted" into a surface, nor can they be reproduced or predicted. As a result, a random match of tape ends is considered very unlikely.

Regardless of its probative value, the identification of a tape fracture match relies on the examiner's opinion in identifying distinctive features across the tape ends. This could become problematic due to the lack of standardized criteria to make match/nonmatch judgements. Thus, there is a critical need to develop such criteria and to assess the validity and accuracy of tape fracture match determinations. In the absence of standard thresholds and associated error rates, the identification of tape fracture matches will remain subjective, and their scientific validity will likely be challenged in court.

Our long-term goal is to develop an effective strategy to qualify and quantify distinctive features in tape end examinations and to develop standard automated algorithms that complement and substantiate the examiner's observations. As a first step, the aim of this study was to establish mechanisms to qualify and quantify tape end match features, develop an approach to estimate threshold values, and evaluate if the assumption that random tape fracture matches are unlikely is supported by experimental data.

In this study, the occurrence of false positives and false negatives was investigated for 2000 blind comparison end tapes (hand-torn and scissor-cut duct tape samples), analyzed by three independent examiners. The combination of physical features, microscopic features, and match scores was used to classify the physical end matching results into five qualitative categories. Match scores were calculated as a relative ratio of observed matching sections per scrim area, with values ranging from 0 to 1, where the closer the number to 1 the more distinctive features observed along the tape ends. Frequency graphs were created to visualize the distribution of true positives and true negatives as well as to define thresholds for match/nonmatch decisions.

Three main tear patterns were observed in the hand-torn tape samples. The most common pattern observed among torn tapes was angled (42 percent), followed by wavy (35 percent), and puzzle-like (22 percent). The microscopic features of the puzzle pattern showed higher match scores (77 percent at 1.0 score and 23 percent at 0.9), while the other two patterns were skewed to 0.9 scores with ~25 percent of the fractures at match scores between 0.5 and 0.8, and a higher incidence of false negatives observed in wavy patterns. The overall accuracy of the test, calculated from the area under the curve of receiver

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operating characteristics (ROC) graphs, was 99.6 percent for hand-torn tapes, and 99.8 percent for scissor-cut tapes, with 0 percent false positives and 1–2 percent false negatives. The results show that false positive fracture matches of duct tapes are uncommon and that variability between individuals and between method of separation were minimal. A sample set of 500 tape ends was further manipulated to simulate normal stretching of the tape ends during crime scenarios, and the error rates and frequency distribution rates were investigated. Relative match scores were found to be a good classifier/predictor for fracture match determinations and are expected to help as a step toward the harmonization of conclusions among forensic examiners.

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POSTER SESSION

Impression and Pattern

Fingerprints on Clothing: Evidence about Fingerprint Visualization on Distinct Types of Fabrics

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Fingerprints are a very important type of evidence in forensic science. In crimes where there is direct contact, fingerprints can be used as conclusive proof. Currently, investigations and research into the visualization of fingerprints on clothing are lacking, although such studies could be very important for specific crime investigations, such as rape, where contact between the offender and the victim's clothes is inevitable.

With the starting hypothesis on the possibility of developing fingerprints on clothing, I began my investigation at London South Bank University. Two different techniques were tested to develop fingerprint visualization (Lumicyano fumes and ninhydrin), and 13 different types of fabrics (mainly used in clothing) were used. These fabrics were carefully chosen to be the most commonly used in clothing worldwide. The color of the fabric was found to be a factor that could affect the performance of techniques, and therefore, both dark and light samples of all types of fabrics were tested. Five samples of each fabric type in black and white (totaling 10 samples of each type of fabric) were analyzed. The fabrics tested were cotton, wool, silk, satin silk, polyester, acetate, linen, cotton (40 percent)–polyester (60 percent), cotton (60 percent)–polyester (40 percent), viscose, nylon, lycra-elastane, and cotton-elastane (3 percent). All fabrics were tested for authenticity using Fourier-transform infrared spectroscopy (FTIR) and a pre-arranged fabrics database. To prevent the occurrence of risks during this research, specific training on fingerprint development with a Superglue cabinet and ninhydrin was undertaken. After all suitable conditions were guaranteed, research using both methods was initiated. The researcher's fingerprints were deposited on clean samples of fabrics under normal, dirty conditions (that is, the researcher did not wash his hands prior depositing the fingerprints).

After a couple of days, the fingerprints became naked-eye visible on some of the fabrics. Different light methods were tested to visualize the fingerprints, and a few fingerprints that were not visible to the naked eye were made visible under UV light. Fabric and chemical control samples were also tested to guarantee their suitability. Fingerprints deposited on white samples were more easily developed with ninhydrin, whereas those on dark samples were more easily developed with Lumicyano fumes. Using the ninhydrin technique, the white acetate fabrics retained the best fingerprint quality. In contrast, polyesters and cotton (40 percent)–polyester (60 percent) samples were the most suitable for the development of fingerprint visualization using Lumicyano. Almost all fingerprints deposited on man-made fabrics were visible using the Lumicyano fumes technique. The development of fingerprints on these different fabrics will be explored in this presentation, with reference to the fabrics that are suitable for the development of decent-quality fingerprints and those that are the most problematic for forensic analysis.

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During all the experiments, pictures that clearly confirm that fingerprints can be visualized from fabrics were taken. In a small number of samples, it was possible to observe some distinctive features of the fingerprint, including their patterns and distinctive characteristics (e.g., bifurcations and ridge endings).

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Potential Impact and Application of 3D Scanning, 3D Modeling, and 3D Printing in Toolmark Examination

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Scope: Although functional 3D-printed products are increasingly available on the market, the implications of their impacts on toolmark and pattern examination remain unknown. The new technology of 3D scanning, modeling, and printing might complicate forensic toolmark examination. However, this technology might also offer new opportunities for the standardization of forensic examinations of toolmark and pattern evidence.

Objectives: To understand the impact of 3D manufacturing technology in toolmark examination, two functional 3D-printed gun barrels were manufactured by 3D scanning, modeling, and printing. The toolmarks and patterns generated during the test-firing were examined.

Introduction: 3D printing is a manufacturing process that can potentially transform a virtual digital model into a real-world 3D solid object. This process is popular for producing prototypes of many designs. The affordability and availability of 3D printing have increased in recent years, and it has emerged as a method of choice for manufacturing functional products in many industries, including firearms. Therefore, proactive studies and research on the implications of this new technology in forensic toolmark examination is needed.

Methods/approach: Currently, no published data for toolmark examinations of bullets discharged from a 3D-printed metal firearm are available. Our approach was to manufacture 3D-printed metal gun barrels to study the impact of 3D scanning, 3D modeling, and 3D printing on forensic toolmark examination. In this presentation, the toolmark examination of bullets discharged from 3D-printed metal gun barrels will be discussed. The 3D modeling was built based on the physical dimensions of the 1911 using computer software with and without the use of 3D scanners.

Results and findings: Because of the rough surfaces of the untreated 3D-printed products, the gun barrels required some hand-fitting to fit into the 1911 frame. The interior of the gun barrel was left untreated. In total, 100 cartridges were discharged from each barrel to examine and compare the striations left on the bullets. During test-firing, the first 50 rounds from both barrels were discharged without incident; however, substantial improper extractions were observed throughout the test-firing, resulting in stove-piped cartridge cases. At approximately the 65th round, the slide started to lock up and did not cycle back to extract the cartridge case. A ball-peen hammer was used to move the slide backwards and expose the fired cartridge case. Multiple attempts were made to clean, dremel, and lubricate the chambers to facilitate extraction; none of these efforts proved successful, and the malfunction continued until the end of the 100th test-fire cycle.

The striations on the bullets were successfully collected and preserved for examination and comparison.

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Conclusion: Post-printing surface treatment of such barrels might be needed to eliminate mechanical malfunction of the firearm. Examining the bullets fired from both barrels revealed that all 100 bullets could easily be differentiated from each other. The individual characteristics of the striations were consistent throughout the test-firing. When comparing the striations on the bullets fired from two identically printed barrels, they could be easily eliminated as having been fired from the same barrel. When the 3D scanning, modeling, and printing process is well controlled, we envision that it may offer a new way to design and produce standard tools for toolmark or pattern evidence examination.

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Progress in Developing a Footwear Randomly Acquired Characteristics (RACs) Reference Collection for Frequency and Spatial Distribution Analysis

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Department of Justice

Footwear impressions are often deposited on a surface when an individual wearing a shoe moves, such as when entering and exiting a crime scene. Once detected and recovered, this evidentiary item can provide valuable investigative linkages to a suspect. A forensic footwear examiner may conclude an identification when there are sufficient similarities between the questioned impression and the known footwear, specifically with regard to attributing the class, wear, and randomly acquired characteristics (RACs). Recently, there have been courtroom challenges regarding the discrimination potential of footwear evidence, particularly when there are mass productions of similarly modeled and sized shoes. To address these challenges, the FBI is currently compiling data on the frequency and spatial distribution of RACs detected on the outsoles and marked using Photoshop™ of more than 1,500 boots with a similar outsole pattern. A visualization of the individualizing differentiation and results to date between marked boots in the database was represented in a heat map.

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Laterally Reversed Latent Prints Detected with Amino Acid Reagents

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United States Secret Service

A laterally reversed latent print is a mirror image of the orientation of the friction skin ridge detail from a finger, palm, or foot that has been left on an item. A number of articles have been written about the transfer of friction ridge detail from one surface to an adjoining or abutting surface (Czarnecki, 2005; Kershaw, 2000; Lane, Hilborn, Guidry, & Richard, 1988). This presentation discussed the laterally reversed print that is on the opposite side of the surface, where the amino acid matrix is absorbed through the porous substrate from the front or top to the back or bottom.

The three demonstrated cases are different types and weights of paper that were processed with the reagent 1,2-indandione using standard protocol and then visualized with either an alternative light source or laser with the proper filtration. Latent prints were developed, and upon further examination, the prints were found to be laterally reversed images that had soaked through the back of the papers. Although 1,2-indandione was used in these cited cases, it should be noted that laterally reversed latent prints have also been developed with the 1,8-diazafluoren-9-one (DFO) and ninhydrin reagents.

Recognition of laterally reversed prints should be included in training modules and procedural protocols for examiners, photographers, technicians, and others involved in the examination or documentation of latent print impressions.

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A Picture Is Worth 1000 Minutiae—A Case Review of Fingerprint Identifications Made in the Photographs of Child Pornography

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This is a case review of the 2015 Dannie Ray Horner child pornography case. After a unique discovery was made by the digital forensic expert while reviewing the files on the suspect's computer, the fingerprint analyst was called in.

What began in late 2014 as an investigation by Homeland Security into the distribution of child pornography ultimately led to a history-making case for the agencies involved. A collaboration between the Sarasota Police Department and the Sarasota County Sheriff's Office brought forth the arrest and conviction of Dannie Ray Horner on 26 charges, including capital sexual battery, molestation, possession, and distribution and transmission of child pornography.

While working on a tip from the Internet Crimes Against Children (ICAC), the Sarasota Police Department developed suspect Dannie Ray Horner. After a thorough investigation of the digital media by the Sarasota County Sheriff's Office Intelligence Digital Forensics Expert John McHenry, a unique discovery was made. Friction ridge detail was apparently visible in several photos of child pornography, and after editing the photographs, they were submitted to the Automated Fingerprint Identification System (AFIS) unit for fingerprint examination.

Digital imagery taken in clear focus by the abuser with his Samsung mobile phone allowed for his fingers to be identified in the photographs of child pornography themselves. This left no doubt as to who was behind the camera and the abuser of a child too young to speak for himself. For this case, the fingerprint identification was key to bringing the case together. This identification prevented the defense from being able to say someone else was in the photos creating the child pornography and abusing the child. The email address that was associated with many of the transactions for distribution was a common email shared by the suspect's business partner at Two Dans Painting. It would have been easy to use the "not me" card as both subjects were named Dan. The fingerprint identification allowed for the State Attorneys to move forward with the sexual battery and molestation charges as there was no doubt as to which "Dan" was responsible.

This case was rather uncharted territory for all parties involved. Several questions and challenges arose from the state and the defense while preparing for this case. Although the suspect's face was never in the photos, having a positive identification to the hands that were causing harm to this child was the ultimate proof needed. Challenges to be discussed include the following:

- Reversing the fingerprint image to mirror that of the traditional latent print
- Visual color distinction when you are used to looking at "black and white"
- Taking major case prints and expressing why they are necessary
- Questioning the true motive behind taking on "a case like this"

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Ultimately, this case demonstrates how still images of an offender's hand can be used to secure a conviction but also highlights how fingerprint detail in any form of digital media can be used in a wide variety of investigations. Furthermore, investigators should always be on the lookout for these opportunities of fingerprint detail in media and work in conjunction with the fingerprint examiners to determine if they are suitable for comparison.

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Is Latent Print Viability Affected by Heat (Accumulated Degree Hours) from 60-Watt Incandescent Light Bulbs?

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There is currently a lack of research in the patterns and impressions field, including how prolonged heat exposure impacts fingerprints. This presentation increased the audience's understanding of how time and temperature as a combined variable impact the viability of latent fingerprints deposited on 60-watt incandescent glass light bulbs. The lack of research regarding the potential effect of varying environmental factors on pattern and impression evidence, as discussed in the 2009 National Academy of Sciences (NAS) report (National Research Council, 2009), was directly addressed. A statistical regression model (using accumulated degree hours as the independent variable) was used to describe the relationship between heat and latent print viability.

In the fall of 2016, the Henrico County Police Department in Richmond, VA, recovered a print from a lightbulb encountered in a burglary case and speculated that it had been removed to prevent suspect identification from CCTV; the defendant, however, asserted that he had touched this light bulb months prior to the crime, and there was no published research from which to assess the validity of this claim. Current research has addressed the detection limits of certain components of fingerprint residue, such as serine, which has been detected by gas chromatography-mass spectrometry after exposure to temperatures of up to 150°C (Birnbaum, 2011). Although this information is valuable, it does not address the practicality of crime scene investigators visualizing and preserving prints or use time and temperature to estimate the time since a fingerprint was deposited.

This project addresses issues not covered by this study by (1) recovering latent prints with conventional methods, (2) evaluating fingerprint quality based on a previously established 11-point scale (Dhall, Sodhi, & Kapoor, 2013), and (3) relating the combined variables of time and temperature in a reliable regression model that can be used to describe the relationship between heat and latent print viability. Through the use of the regression model and popular fingerprint recovery methods, this study will provide sound evidence for the persistence of latent fingerprints and provide law enforcement with additional information that can be useful during the course of investigations.

In performing this study, 10 light sockets were mounted on five strips of shipping wood and wired in parallel to provide equal amounts of electricity to each bulb. Each 60-watt incandescent lightbulb was secured into each light socket with gloves. Once secured, nine fingerprints were deposited on each bulb with medium pressure. A 12-hour baseline test was performed to determine the best length of time to leave the bulbs on for subsequent testing. After the baseline test, the units were turned on for 18 hours, 48 hours, 72 hours, 120 hours, 168 hours, 240 hours, 336 hours, 504 hours, and 672 hours. A thermal imaging camera monitored the units to record the generation of heat from different parts of the bulbs. After each allotted time period, the prints were enhanced with black powder and lifted with tape on to a lifting card to be examined for quality using an 11-point scale.

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Latent prints were recovered through the baseline test (1,488 ADH); thus, the units were left on longer. Latent prints were still recovered after 18-hour heat exposure (2,813.4 ADH). Of the 81 prints recovered, 54 ranked within the top half of the 11-point scale and were identifiable. Similar results were obtained after 48 hours (7,502.4 ADH) and 72 hours (11,253.6 ADH). During these tests, 89 and 83 latent prints were recovered, and 58 and 61 were deemed identifiable, respectively. Additionally, latent prints were persistent and proven recoverable after 5 days (18,756 ADH), 7 days (26,258.4 ADH), 10 days (37,512 ADH), 2 weeks (52,516.8 ADH), 3 weeks (78,775.2 ADH), and 1 month (105,033.6 ADH). Prints insufficient for identification were often adversely affected by moisture in the print and movement when the print was deposited, which occurred independently of heat.

In conclusion, the persistence of latent prints exposed to heat over long periods of time supports the persistence of latent prints, could provide valuable information to law enforcement, and is an important addition to the body of work in the field of pattern and impression analysis.

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Time Lapse Case Study of Atypical Hyperlinearity and Effect on Friction Ridge Skin Visibility

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In the fingerprint community, the common rule of "thumb" is that the amount and severity of creases within an impression is directly correlated to the age of the subject. This information is spread as common and reliable knowledge, but this mantra should be checked when analyzing particular individuals. This presentation is a case study on the author, who even in her teenage years experienced extreme creasing with no disease status.

Mrs. Meredith Coon has conducted a time-lapse study of atypical hyperlinearity (heavy creasing) in her fingerprints since she was 19 years old. Over the course of the 10 years that followed, she has recorded her fingerprints at regular intervals. Mrs. Coon's fingerprints demonstrate that although heavy creasing is often attributed to advanced age, young adults can also display such traits. The creases in her fingerprints are so prevalent and pronounced that some of her fingerprint recordings are unusable for identification. This presentation will incorporate images of Mrs. Coon's fingerprints recorded at various intervals over a 10-year period.

This creasing is very dramatic and completely obliterates the friction ridge details, especially when the skin is dry. This condition also appears to affect other members of the author's family and does not appear to worsen exclusively with age but is adversely affected by environmental factors. Repeated recordings of the author's skin and that of family members are used in a time lapse fashion to demonstrate the severity of creasing and the unpredictability of the friction ridge recordings.

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Enhanced Reflected Light Microscope Imaging with Reflection Transformation Imaging Methods and Open Source Software

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Ossi Imaging

Most reflected light microscopes use some form of oblique illumination when viewing most specimens, except for polished metallurgical preparations. The directionality of the light provides textural information to the examiner. Many microscope manufacturers now offer light-emitting diode (LED) ring light illuminators for stereo microscopes and darkfield illuminators for compound microscopes outfitted with user-assignable segmentations, suggesting the importance of controlled directional oblique illumination. Although progress is being made, these advancements alone are currently insufficient to employ the method outlined below because many illumination trajectories are required. This method requires oriented directional light sources that are sequenced during image collection. Processing with open-source software reveals specimen topography and textures that might not otherwise be visible. Image collection methods can be used with any light microscope with sufficient objective working distance and any light source that can be repositioned around the specimen.

Reflection transformation imaging (RTI) is a photographic image collection and computational display method that captures surface images of opaque specimens. Post processing the images allows interactive re-lighting of the subject from any direction. Polynomial Texture Mapping open-source software developed at Hewlett Packard permits the mathematical enhancement of the subject's surface shape and color attributes. The enhancement functions of RTI reveal surface information that may not be apparent to the unaided eye or other observational methods. Oblique reflected light illumination is the most common way to view specimens. Light strikes the specimen at an angle off the optic axis. Single images taken with unidirectional light accentuate topographic features, making the illuminated side of a feature bright, contrasted against the shadow side. RTI methods suggest collecting up to 64 images using a unique lighting azimuth/compass direction for each image. The specimen, optics, and camera remain fixed with only a single, near point source of light changing to a new location for each image. This method is outlined and the associated open-source software demonstrated in comparison to traditional microscope collection methods.

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Shoeprint Lab Survey

In 2009, NAS published a report named *Strengthening Forensic Science in the United States, A Path Forward*. Among the common issues noted in this report was the lack of common quality assurance demands and working procedures of all forensic laboratories. Substantial effort has been invested in promoting these issues since this report, and the survey presented here was performed to gain a sense of the current situation of shoeprint laboratories and help focus on aspects that need reinforcement.

The subjects approached in this survey concern the quality standards of the laboratories, the requirement for expert certification, the work load, and comparison and reporting procedures. The survey was distributed to laboratories worldwide. The participating laboratories were contacted using several methods. A personal request was sent to experts who were personally acquainted with the authors. They were requested to forward the survey to other laboratories they were familiar with. In addition, a link to the survey was posted on a professional-oriented social networking site. Anonymity was promised.

The distributions of responses to the various questions were analyzed, and the relationships among them were examined using Pearson correlation. Sixty-nine responses were received from various laboratories. Approximately 50 percent of the answers were received from Europe, ~30 percent from North America, ~15 percent from Oceania (Australia and New Zealand), and the rest from other continents. Of the laboratories that answered, 43 percent are national, 17 percent regional, 30 percent local, 3 percent academic, and 4 percent private. Most laboratories employ no more than three practitioners, and ~70 percent handle no more than 100 cases annually. Nearly 80 percent of the laboratories have fully written working procedures, and only 9 percent have no written procedures at all. Most of the laboratories are accredited (77 percent), and the vast majority of them have International Organization for Standardization (ISO) 17025. Most of the laboratories perform proficiency tests (87 percent), and of them, 65 percent perform them once a week and 23 percent twice a year. The proficiency tests come from various sources. The most popular commercial test is distributed by Collaborative Testing Services (CTS), but there are several other companies as well. Most European laboratories perform the European Network of Forensic Science Institutes (ENFSI) test. Several laboratories perform their own proficiency tests.

The effects of the geographical region and whether it is central or local on accreditation, standard operating procedures (SOPs), cases per year (per person), comparison method, required education, number and type of proficiency tests, international certification, training (time and requirements), verification, and exposure to background information were studied.

The presence of correlations between the different internal requirements (education, SOPs, accreditation, bios, verification, and training requirements and period) were examined, and whether a correlation existed between the personal work load and quality control (accreditation, written SOPs, verification, proficiency tests, and training period) was also investigated.

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Most of the answers were received from laboratories in Europe and the United States. It is also probable that because of the data collection method, the results presented may represent the situation in well-established laboratories as opposed to small, isolated ones.

This presentation addressed the subjects mentioned above, suggested possible explanations for the differences among laboratories, and recommended actions to further promote standards for shoeprint laboratories.

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Dependence Among Randomly Acquired Characteristics on Shoeprints and Their Features

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The 2009 National Research Council (NRC) report, *Strengthening Forensic Science in the United States: A Path Forward*, and the recent President's Council of Advisors on Science and Technology (PCAST) report to the President, *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods*, call for improving the scientific basis of forensic procedures. This presentation examined basic assumptions in the field of shoe comparison currently used to define the degree of rarity (DOR) for a given shoe sole.

Footwear examination starts with comparing the size, pattern, and wear of the shoe in question to the print found in the crime scene. Then, the sole's DOR is calculated based on the randomly acquired characteristics (RACs) that scar its contact surface. These marks are caused by abrasions on the outsole. Unlike manufacturing flaws, the creation of RACs depends on the owner's walking patterns, the material of the shoe sole, the surface with which it comes into contact, the pattern of the shoe, and its wear and tear. RACs are characterized by several features, such as their location, orientation (angle), and shape, which are used to compare shoes.

Previous studies assume that the features of a given RAC are independent of each other, as are the RACs themselves. Therefore, the DOR of a single RAC is calculated by multiplying the probabilities of its features, and the DOR of the entire shoe is calculated by multiplying the DORs of all its RACs. However, if the independence assumption does not hold, the calculations would be incorrect, and the rarity of a certain shoe may be overestimated. The goal of this presentation is to statistically test the independence assumption.

The focus is on the relationship among the features of a given RAC using data collected by the Division of Identification and Forensic Science. Three propositions are tested; each contends that the RACs are created randomly and independently on the shoe sole, but each also includes the following:

- The shape type of the RAC is independent of its location.
- The orientation of the RAC is independent of its shape type.
- The orientation of the RAC is independent of its location.

The null hypothesis of independence includes two parts. First, it assumes that RACs are independent; thus, the occurrence of a particularly configured RAC does not predict the occurrence of another with a certain configuration. Second, the hypothesis assumes that RAC features are also independent (i.e., the shape type distribution does not depend on the RAC's location or orientation). Under the null proposition, this statistic has an approximately $\chi 2$ distribution. The larger the value of $\chi 2$, the more evidence exists against independence.

The propositions above were tested and rejected, showing that an association does exist among the features. Two analyses were conducted to control for the effect of the sole pattern. Association was found between the shape type and location and between the shape type and orientation, even within a specific shoe

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pattern. The calculation of the DOR as a product of probabilities is, therefore, invalid, and the dependence should be modeled for a well-founded evaluation of the DOR.

The elements that make up the shoe sole comprise an important feature that affects the creation of RAC. The analysis accounts for the shoe sole patterns, but because they consist of a large number of different elements, a more detailed analysis is required. Using three sample patterns, this study demonstrated how the dependence between RACs' features and shoe sole patterns can be tested. These questions and similar issues regarding the possible reasons for these dependencies were investigated and were analyzed and discussed in the presentation. Using a data set of approximately 380 shoes, RACs and their features were determined to not be independent of each other or the shoe sole pattern. Some of the dependencies found are probably caused by pattern elements.

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JUST WHEN YOU THINK IT'S A FINGER...

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This was a homicide investigation involving a female victim found buried in a rural area of Arizona. Identification of the victim and further investigation led detectives to an apartment where a male subject lived. He was the last person to have seen the victim alive. A search warrant of the residence was conducted and included searching it for visible and latent bloodstains, both of which were found. Among the visible bloodstains was a patent impression in blood on the back of a kitchen chair. The patent impression was photographed on scene, and photographs of this impression were later used in a latent comparison. The impression contained a large loop, believed to be a right slant loop, specifically a thumb print. A comparison of the impression was made to the victim and male subject and initially, the impression was excluded to the fingerprints of both subjects. An Automated Fingerprint Identification System/Next Generation Identification search was conducted using the search criteria of a finger with a right slant loop with negative results.

The item of evidence was then re-examined in a laboratory setting, and additional friction ridge detail, found around the edge of the chair, was noted and photographed. This detail helped in the identification process because of its presence and location and aided the latent examiner in determining that the loop pattern was made by a palm, specifically the interdigital area of a right palm. The impression was compared to the known prints of the victim and suspect and was identified as having been produced by the male suspect.

This is a case of a latent examiner having tunnel vision and focusing on one aspect of an impression. It is also a case that brings to light the importance of physically seeing an item of evidence and examining it wholly, rather than relying on photographs of the evidence to do a latent comparison. If the examiner had been able to more thoroughly examine the actual item the impression was found on prior to doing his first comparison, the suspect would have been identified during the initial comparison.

*This case is still active and awaiting trial.

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Policy Decisions In Latent Print Examination Affect Specificity

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The assessment of the value of latent print impressions is often defined in an agency's standard operating procedure. Policy decisions regarding the approach to determining value can change the number of impressions that will be retained and compared by examiners.

Latent print examination uses two main approaches to determine the utility of an impression, as defined by the Scientific Working Group for Friction Ridge Analysis, Study and Technology (SWGFAST). In one approach, impressions that cannot be identified will not be preserved, documented, or retained. In the second approach, impressions that cannot be identified but can be excluded are preserved and compared. More recently, a third approach to define which marks cannot be excluded but can be identified has emerged: value for identification only. While none of these approaches is wrong, each has a different false-negative rate and affects specificity. This lecture explained how changes in policy can impact specificity. The intent is to introduce examiners and policy-makers to the concepts of sensitivity and specificity and how changes might impact the criminal justice system by providing real examples from erroneous conviction cases.

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An Investigation of the Factors Necessary to Produce Three-Dimensional Fabric Impressions in Automotive Finishes

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In some vehicle-pedestrian collisions, patterns from clothing fabric may be impressed into the surface coatings of the hood, front fascia, bumper, and fenders. Occasionally, patterns are found in headlamp assemblies and other polymeric vehicle components. Generally, the focus in these cases is the association of physical evidence, such as biological material, paint, and glass, collected from the scene, victim, and suspect vehicle. 3D fabric patterns impressed onto vehicles often contain embedded fibers, and these fibers and patterns may assist in providing important associative evidence. The force required to produce these patterns, which could yield important information regarding vehicle velocity at impact, has received little attention. The aim of this study is to elucidate the various factors involved in the production of 3D impressions. Variables studied include the type of fabric (structure and composition), surface coating, angle of impact, and impact force. This study utilizes used two impact devices located within the Pennsylvania State University College of Engineering's Civil Infrastructure Testing and Evaluation Laboratory (CITEL): a pendulum impact tester (6- foot arm) and a drop-weight impact testing device (10-foot drop height).

The pendulum impact tester utilizes a dome-shaped weld cap mounted to the front of the arm at its end. It is covered with a layer of foam and the test fabric to simulate a clothed human kneecap. The impact site of the pendulum arm is permitted to collide with vehicle components that are cut to an approximate 23 cm by 23 cm square, which is clamped to a rigid metal backer plate. To vary the impact force, the pendulum arm is raised or lowered; weights can be added to further increase the impact force. The precise impact force is calculated by analyzing high-speed video recorded with a Phantom V711 digital camera.

The drop-weight impact testing device consists of a cylindrical 14.8-kg steel weight suspended by a pulley in a clear polyvinyl chloride (PVC) pipe guide. A layer of fabric is placed over a 10 cm by 10 cm section of vehicle component. A stainless-steel disk is positioned at the base of the guide tube over the fabric and vehicle component. To vary the impact force, the drop height is raised or lowered; additionally, the diameter of the stainless-steel disk can be altered to disperse the impact force over a smaller or larger area. The precise impact force is calculated based on the drop weight, height, and impact area.

With fabric type, surface coating, and impact angle held constant, preliminary results show repeatable fabric imprint pattern formation, provided a minimum pendulum height is reached. This permits the determination of the impact force and assessment of pattern production as other factors are varied. Initial evaluations of the patterns on each vehicle component, both pre- and post-impact, were conducted using stereo microscopy and micro-level terrain mapping of the fabric using a Leica DVM6 digital microscope. Other variables, including the angle of impact, surface coating, surface treatment, and fabric type, will be examined in future studies.

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Applying Reflection Transformation Imaging Methods and Open Source Software to Tire Tread and Shoe Print Image Collection

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Ossi Imaging

Tiretread and shoeprint images contain textural information. The accepted image capture methods suggest collecting three images with the light source at a low azimuth angle. Only the light source compass direction is moved 120° after collecting each of the three images. Although molds may exist, the original impression evidence is not retained. Collecting images at additional light source directions, as outlined in the methods below, will allow examiners to extract additional information in the future that might not otherwise be available. The downside is that additional time might be required to collect the additional images. The outlined methods offer a pathway to accelerate the image collection process and eliminate the need for a lighting assistant.

RTI is a photographic image collection and computational display method that captures images of the surface of opaque specimens. Post processing the images allows interactive virtual re-lighting of the subject from any direction. Polynomial texture mapping, an open-source software developed at Hewlett Packard, permits the mathematical enhancement of the subject's surface shape and color attributes. The enhancement functions of RTI reveals surface information that may not be apparent to the unaided eye or by using other observational methods. Oblique reflected light illumination is the most common way of viewing specimens. Light incidents the specimen at an angle off the optic axis. Single images taken with a unidirectional light accentuate topographic features by making the illuminated side of a feature bright, contrasted against the shadow side. RTI methods suggest collecting up to 64 images and using a unique lighting azimuth/compass direction for each image. The specimen, optics, and camera remain fixed, and only the single quasi-point source of light changes to a new location for each image. This method is outlined, and the associated open-source software is used to illustrate the resulting enhanced images. This method can be used with almost any camera and appropriate light source.

The collection of 64 images is time prohibitive and may require the employment of an assistant to move the light source following the collection of each image. Because tiretread and shoe impression features are often linear, reducing the total number of images collected along the specimen's axis and using an electronic flash movable array should make image collection times reasonable while offering the additional images that examiners might need.

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Incorporating a Statistical Model into Forensic Shoeprint Analysis

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To date, there is little statistical backing that can be applied to forensic shoe print analysis. Current methods of data collection include shoe sole powdering and scanning. We begin data analysis by scanning a sample of shoes and compiling them into a database. The samples collected include five different shoe sole patterns with two pairs of each type. We collected five images of each individual shoe. The objective of this image collection is to compute the Hu moments present in each individual shoe. Hu moments are eight points invariant to scale, rotation, and translation. The sensitivity to change of these moments makes them potentially useful in identifying the unique characteristics of any given print. The Hu moments corresponding to the images are then used in the training of a statistical model. This model can provide a score indicating whether an individual shoe would be a match with each element of the established database.

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Shoeprints: The Path from Practice to Science

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The 2009 National Academy of Sciences (NAC) report and the 2016 President's Council of Advisors on Science and Technology (PCAST) report, made it clear that many traditional forensic disciplines have not evolved with the broader scientific community, particularly with respect to the lack of modern statistical approaches and quality control measures. The 2009 NAS report, which evaluated and set required standards for the various forensic fields, caused an earthquake in the forensic community. Some of these aspects standards were addressed in the 2016 PCAST report and identified future thresholds for courts in the USA.

For most fields of forensic evidence, current methods fall short of a scientifically objective and quantitative analysis that can be presented in court when trying to determine a match between samples.

This presentation focused on footwear analysis. The identification of footwear impressions is based on the comparison of a print found at the crime scene with a test impression made from a suspect's shoe. Weight is given to the RACs that result from random processes of wear and tear, such as holes, scratches, etc. One of the common methods currently used to present the level of confidence in the connection between the test impression and the crime scene print is an ordinal scale, such as the SWGTREAD (Scientific Working Group for Shoeprint and Tire Tread Evidence) scale, which is a subjective approach to the estimation of confidence or significance, rather than one based on an explicit statistical model. The current method of evaluating RACs clearly reduces the potential suspects' shoe population, but it lacks formal statistical analyses based on large databases and fails to provide a scientific and quantitative scale for assessing the match between a crime scene print and a suspect's shoe.

Current challenges of evaluating shoeprint evidence from the collection stage to the submission of testimony in court were surveyed. Practical recommendations and initial scientific steps were proposed to carry the shoeprint comparison field along the path from practice to science.

The complexity of the shoeprint comparison process requires high practice standards both for the lab and for the practitioners. A detailed standard operating procedure (SOP) is needed to ensure that the work is preformed professionally and based on a standard working procedure. This minimizes error, makes the procedure more objective and less operator dependent and increases the transparency of the process. Laboratory accreditation by an exterior institute is another safety net to prevent careless work. Working by SOP in an accredited laboratory assures working standards. Proficiency tests ensure professional working quality. Each practitioner in the lab successfully performing the proficiency test at least once a year is necessary to safeguard a basic level of professional competence. Blind proficiency tests can ensure an even higher level of competence.

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Forensic laboratories should establish routine quality assurance and quality-control procedures, including blind testing and performance testing to guarantee the accuracy of forensic analyses and the work of forensic practitioners as well. Blind proficiency tests can be created internally or collaboratively by several cooperating laboratories. In such tests, the examiner is not aware that the test cases are not real ones. For performance testing, sample cases are re-examined by other experts or the same experts after a period of time and the results are compared.

Verification is a key step for preventing error during routine case work. After an examiner reaches a conclusion and writes the report, a second expert reviews the case. The optimal form of verification is to perform a blind comparison independently and then to compare the results with the original report (double blind) to prevent confirmation bias. Contextual bias may influence decision making during the working process, hence should be minimized as much as possible. Maintaining high lab standards cannot be complete without investing in the professional training of the examiners. A scientific background is recommended for all examiners. Academic scientific studies educate practitioners in logical and systematic thinking, and the limitations of human knowledge, which is a basic need of the forensic practitioners' work. Specific training in the profession of shoeprint comparison should be a major step before the examiner is permitted to write expert opinions. This should be limited to certified examiners.

A crucial issue is that the current procedure involves almost no statistics that are based on large-scale datasets related to either class characteristics or RACs, since these are not available. The distribution of shoe-sole patterns in a specific geographic area constantly changes. The shoe industry changes the patterns sold periodically, and people regularly replace their old shoes with new ones. For this reason, keeping an up-to-date database of shoe soles to assist in statistic calculations challenging.

The aforementioned studies use very simple statistical tools. The work that has been done triggered the need for ongoing statistical research which includes developing a model that explains the creation of RACs, adjusting statistical calculations according to the relevant population in each casefile, estimating the covariance structure of RACs and analyzing the crime scene noise by the use of experiments. An example of the latter would be the collection of noisy shoeprints by conducting a controlled experiment and comparing the prints from the experiment to the test impressions made from the shoes under controlled conditions.

Automated systems, if developed, can assist the examiners in reaching objective conclusions. For example, an automatic system that finds the shoe pattern on crime scene print prior to observing the suspect shoes or an automatic system that will find the RACs and an examiner will approve them, would both reduce confirmation bias.

Medical diagnostics is a field facing similar challenges as forensic science in assessing the performance of human expert examiners working with complex data. both rely on expert human capabilities which cannot be readily reduced to a set of objectively defined rules and both face the need to continuously upgrade professional skills. The capability and knowledge base of practitioners may be difficult to measure effectively in each area. The approaches developed by the medical society to handle these challenges could be adapted by the forensic community as well. The overall performance of the expert, a physician or a forensic expert, should be addressed as a "Black Box," which gives a nontransparent result to the effectiveness of the expert, based on empirical tests of performance. In contrast, "White Box" tests attempt to understand aspects of how expert examiners make decisions.

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Case Study of a Robbery Which Turned into a Homicide

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This is an interesting case that occurred in August 2009 in an affluent area of Cave Creek, Arizona. I was called to the crime scene, which contained a large beautiful house with an older deceased man just inside a partially open front door. He was tied with electrical cords behind his back and was face down on the floor.

My duty was to try to collect all the evidence within this crime scene and obtain evidence of a suspect. This case study took attendees through the crime scene methodology. This presentation also included the human element of the crime scene processing. I covered what went right with the crime scene processing and impression evidence and what lessons I learned about what not to do. This presentation also addressed the importance of teamwork and being part of a good crime laboratory when working a large case with an enormous amount of impression evidence. I took attendees through the search for the shoes with the impressions that matched those found within the home. Additionally, I reviewed the importance of a latent examination for a suspect found with a crucial area within the crime scene.

My goal was to conduct a review of the two trials that were held in Maricopa County Superior Court. I reviewed the verdicts and went over the evidence and the importance of the evidence in the convictions of the suspects.

Finally, I reviewed the importance of the complete processing of a crime scene and how the most insignificant pieces of evidence can make a substantial impact on the jury. DNA is not always the guiding factor in jury judgement. I emphasized how missed details can ruin cases.

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Barrier Penetration Characteristics of PolyCase Inceptor ARX Ammunition

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Introduction: Recently, a new entry into environmentally friendly ammunition has appeared on the commercial market. The PolyCase ammunition company, out of Savannah, Georgia, has created a new bullet design and construction. PolyCase ammunition has some novel design features in all its marketed products, specifically the construction and unique shape of its ARX bullet. Prior studies by the authors and other researchers have shown that traditional jacketed and hollow point bullets have predictable interactions with many yielding and nonyielding intermediate substrates. The newly marketed ARX bullet behaves quite differently. Not only is the bullet lead-free, but it also comprises copper spheres in a polymer matrix, manufactured using an injection molding process. This manufacturing process does not lend itself to a traditional hollow point design, however, the bulletsmiths at PolyCase have devised a unique alternative to a cavity in the form of three large flutes in the ogive of the bullet. These flutes create characteristic triangular perforations in automobile sheet metal.

Methods/approach: Several calibers and styles of PolyCase-brand ammunition were test-fired at various barriers, including drywall, paneling, plywood, architectural glass, windshield glass, and sheet metal of different thickness gauges. Automobile sheet metal provided the most characteristic bullet holes when perforated by the fluted ARX bullets as compared with traditional hollow point or full metal jacket bullets. The results were replicated using firearm barrels, with both left-hand and right-hand twists, and different barrel lengths, which offered slightly different velocities as measured with a chronograph near the muzzle. In addition to assessing the bullet hole itself, high-speed photography revealed that a piece of metal was being dislodged from the substrate by the bullet's impact. To capture these "punchouts," ballistic gelatin was placed near the exit holes of the bullets and allowed recovery of the small metal pieces that were dislodged.

Results and findings: Sheet metal pieces that simulated automobile body parts were positioned a few feet from the muzzle of several different firearms and were fired upon using the PolyCase Inceptor ARX ammunition. The fluted ARX bullets consistently created triangular holes in the sheet metal. The larger the caliber, the larger the size of the triangle, however, alternating firearms with different barrel rifling twist directions did not have a visible effect on the shape of the holes created.

The ARX bullet was "deconstructed" by dissolving the polymer matrix and evaluating its IR spectrum to determine that it was nylon. The metal spheres were examined using scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) to assess their relative size, shape, and metallurgy. The bulk of the mass was obtained from copper spheres, but being less dense than the lead core of a traditional bullet, the ARX bullet traveled at a greater velocity than its traditional counterpart.

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Conclusion: Reproducible triangular holes were made in sheet metal by the PolyCase Inceptor ARX bullets. Traditional bullet designs from other manufacturers do not produce triangular holes. Triangular punchouts were recovered from the recovery medium (ballistic gelatin blocks) positioned directly downrange of the sheet metal, along with witness panels to keep track of secondary missiles and post-impact bullet fragments.

The fluted ogive of the PolyCase ARX bullets produces characteristic holes in sheet metal. The style of bullet hole morphology can be readily distinguished from traditional hollow point and full metal jacket bullet types. Recognition of this unique style of perforation may provide useful information for shooting scene reconstructions.

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Duct Tape Physical Matching by Various Separation Methods Using Quantitative Analysis

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Duct tape is often associated with criminal activity and can be used as an evidentiary link between the suspect, victim, and crime scene. Physical matching is the strongest association in forensic science comparative examinations and has a significantly high evidentiary value. This study was designed to further the results obtained by McCabe et al. (2013) by statistically evaluating the error and accuracy rates associated with duct tape physical matching. A blind study analyzing four methods of separation of five brands of duct tape was conducted by an untrained analyst. The lowest accuracy observed was 91.50 percent, the highest false-positive rate was 10.00 percent, the highest false-negative rate was 6.74 percent, and the highest inconclusive rate was 2.25 percent. Overall, the results showed that an untrained analyst can obtain high accuracy (96.61 percent) and low misidentification rates (3.33 percent). This study further confirms the high degree of certainty associated with using the physical matching technique in identifying duct tape samples as matching or nonmatching. The study also shows that different brands, grades, and separation methods have varying contributions to misidentifications and inconclusive rates.

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Trace

Statistical Characterization of Commercial and Homemade Aluminum Powders in Explosives Using Automated Particle Micromorphometry

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Starting materials for an improvised explosive device (IED) are readily obtainable from local commercial sources. Aluminum (Al) powder, a common metallic fuel, has a wide variety of legitimate uses and is widely available without significant regulatory constraints (Kosanke & Kosanke, 2007). Al powders can be obtained from industrial manufacturers or can be produced inexpensively using basic instructional manuals and videos. Due to the online sharing of instructional manuals and published books on how to construct IEDs, bomb-makers are now informed on the easily accessible household materials that can be used to make explosive chemical mixtures (Larabee, 2015).

Previous results using scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) showed morphology and surface characteristics can differentiate some methods of Al powder production (i.e., industrial vs. home-made) (Baldaino, Hietpas, & Buscaglia, 2017). Particle micromorphometry may be used as a complementary method to gain additional information to differentiate Al powder sources. This presentation addresses fundamental factors of Al particle metrology including sample slide preparation, imaging parameters, and potential methods to minimize sampling biases; the statistical methods used to analyze these large multidimensional datasets will be discussed.

Al powder samples were obtained from legitimate industrial manufacturers, various "in-house" production methods, and seized IEDs. The amateur methods were replicated to produce Al powder from easily available sources including: Al foil, metallic spray paints, Al ingots produced by melting from Al cans which were then filed or lathed, pyrotechnics, and catalyst packets from binary exploding targets. To prepare microscope slides for imaging, a subsample containing ~1000µg from the bulk Al powder was placed into a microtube containing Permount® mounting medium. The solution was mixed until evenly dispersed and then an aliquot of the subsample was placed dropwise onto a microscope slide and a cover slip added. To determine the appropriate number of subsamples required to adequately represent the bulk Al powder, a subset of 17 Al powder samples were prepared using 10 subsamples and three3 aliquots for each subsample (i.e., 30 aliquots in total per sample). Leave-One-Out Cross-Validation (LOOCV) was performed on this subset of samples; and it was determined that seven subsamples of the bulk Al powder and three aliquots for each subsample (i.e., 21 aliquots per sample) were sufficient to obtain a representative sample of the bulk Al powder.

Transmitted light microscope images (n≈4,200 fields of view/sample) of the Al samples were acquired using an automated stage and automated Z-focus. Dimensional analysis was calibrated using a National Institute of Standards and Technology (NIST)–traceable stage micrometer; polystyrene spheres of 100µm, 50µm, and 10µm were used as secondary standards to assess linear calibration. Images were batch processed using commercial image analysis software and

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customized code. Each image was converted to a binary image to enhance edge detection, and the particles were counted and measured. Seventeen parameters were measured for each particle within the image field of view including: area, aspect ratio, perimeter, roundness, mean diameter, mean feret, radii (maximum and minimum distance from particle centroid to edge), radius ratio, box height, box width, and fractal dimension. The large multidimensional datasets (n≈90,000–500,000 particles/sample) were analyzed using an open-source statistical package.

The datasets are too large and complex to analyze at this point without some dimensionality reduction. Our preliminary work focused on the use of a weighted summary of 17 morphometric measurements on the subsamples. This was achieved by first taking weighted averages of the particles per fields of view (FOV), yielding a 17-dimensional vector for each FOV (i.e., average particle for each FOV). Then, the average of the average vectors for each FOV per aliquot was calculated, giving a 17-dimensional vector per aliquot. Likewise, the average vector across the aliquots corresponding to a given subsample was calculated, resulting in one 17-dimensional vector for the entire subsample for each sample. The classification accuracy between sources of Al powders using this weighted approach and results from the various multivariate statistical methods tested will be presented.

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The Evidentiary Significance of Automotive Paints from the Northeast: A Study of Red Paint

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This research was completed to provide data relating to the significance of automotive paint chips found in a specific population. Research has previously been conducted regarding Midwestern automotive paint populations (Palenick, Palenick, Groves, & Herb, 2016), as well as populations regarding the layer chemistry of the paints (Zięba-Palus & Borusiewicz, 2006). But to date, no research has been conducted on automotive paints from the Northeast. This research looks at paint samples from the Northeastern portion of the United States and uses both common and emerging techniques for automotive paint analysis.

The populations of automotive paints are constantly changing, and thus need to be thoroughly monitored. By investigating these populations, forensic scientists can begin to understand the significance each individual automotive paint may hold. In order to do this, the physical appearance, layer structure, and layer chemistry can be analyzed to provide a forensic examiner with more detail that can be used to give strength to a conclusion made during an automotive paint examination.

This population study involved the discrimination of red automotive paints using a comparative analysis approach and data analysis. The red samples were chosen as a target group from a larger automotive paint population based on popularity among consumers and manufacturers. The first portion of the analysis used stereomicroscopy, brightfield, and polarized light microscopy to analyze all samples collected in the population. This study has analyzed the paint samples from approximately 200 automobiles ranging from the years 1989 to 2017. The macroscopic and microscopic characteristics of each sample analyzed included relative surface color, presence of effect pigments, relative size of effect pigments, number of different pigments, number of layers, layer color, layer texture, and relative thickness of the layers. The population data obtained varied from previously released reports from Midwestern (Palenik et al., 2016) and North American (Axalta Coating Systems, 2016) automotive paint populations. The Midwestern study analyzed 300 samples, and the North American study was conducted on a much larger scale, but each one demonstrates the importance of this type of study. For example, the present research had a 20 percent gray-colored frequency, which differed from the less than 10 percent obtained in the Midwestern study and 16 percent in the North American study. The target color of red had a 13 percent frequency in the current study, compared with 15 percent in the Midwest study and 10 percent in the North America study.

Next, only the red automotive paints were further analyzed using a comprehensive sequence. This helped to determine the differentiating power of the analytical sequence as well as to analyze the chemical properties of similarly colored paints. Current laboratory methods were used to analyze the red automotive paints, including ultraviolet-visible microspectrophotometry (UV-Vis MSP), scanning electron microscopy/electron dispersive X-ray spectroscopy (SEM/EDX), and Fourier transform infrared spectroscopy (FTIR). In addition,

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this research used Raman microspectroscopy, an emerging technique for automotive paint analysis that has been demonstrated to provide valuable pigment information (Palenik et al., 2016).

This study was conducted to highlight the significance of automotive paint comparisons and the characteristics each sample possesses. The frequency data and the degree of differentiation is important information as it can provide a foundation for determining the significance of indistinguishable samples.

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An Investigation of Chemometric Spectral Transfer Methods for the Forensic Analysis of Traditional Nail and Gel Polishes

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Fragments of fingernails are a type of trace and transfer evidence found at crime scenes or on suspects, especially in cases in which the victim utilized self-defense. In today's society, wearing nail polish is very common, and billions of dollars are spent on nail polish each year. Attenuated total reflection (ATR)–Fourier transform infrared (FTIR) spectroscopy can be used to quickly and reliably differentiate between traditional nail and gel polishes, allowing for the identification of a polish found as evidence by comparing it with a known polish in a database. This research aimed to create a spectral database of several different red and pink traditional nail and gel polishes of various brands as well as calibration models that allow for the proper identification of samples analyzed on different FTIR spectrometers.

ATR-FTIR spectroscopy can detect the chemical components in traditional nail and gel polish samples. Additionally, through chemometric analysis, it is possible to analyze differences in the spectra of each polish or gel and to distinguish between the samples. It has previously been demonstrated that by using chemometrics, one can differentiate between polishes and gels and identify a sample as a specific brand and a specific color within that brand. This research focused on testing the ability of different instruments to perform these classifications, which would then enable the creation of a polish database.

The nail polish collection used in this study contained 49 different traditional polishes from seven different brands and 49 different gel polishes from seven different brands, totaling 98 bottles. All gel samples were cured under a UV light for 3 minutes. On three different ATR-FTIR spectrometers, five spectra were collected for each polish, totaling 490 spectra for each instrument, and a grand total of 1470 spectra.

The spectra for one instrument were analyzed by the chemometric software Solo (Eigenvector Research, Inc.). The spectra were preprocessed using Multiplicative Signal Correction (MSC), which corrects for multiplicative effects and baseline offset. A chemometric technique called "K" Nearest Neighbors (KNN) was used to classify the spectra. Each of the 98 bottles was assigned a class corresponding to brand and color. Each class contained the five replicate spectra of each polish. KNN works by plotting all the spectra based on the absorbance value at each frequency and measuring the distance between an unknown sample and all the other samples in the database. KNN will assign the class of the unknown sample according to the three closest samples in the database. Using MSC and KNN, the software was able to perform an 84 percent correct sample bottle classification and a 100 percent correct brand classification.

To improve these results, Generalized Least Squares Weighting (GLSW) was used. GLSW works by determining which variables in a spectrum are important in describing "clutter," defined as noise and other real phenomena that are unrelated to the object of interest. These variables are then de-weighted, allowing the variables that are important to distinguishing between the traditional nail and gel polishes to be identified more easily. Using MSC and GLSW data

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pretreatment, KNN generated a 98.6 percent correct sample bottle classification and a 100 percent brand classification. In no case was more than one replicate misclassified.

Creating a model that can correctly classify the polish samples by brand and bottle was the first step. The second task arose from the fact that no two instruments of the same type produce exactly the same spectra, making it unlikely for a spectral database to work properly on instruments other than the one on which the database was created. There are two options for the success of a spectral database. The first would be the construction of a chemometric model on each instrument used to identify samples, which is not ideal, cost effective, or practical. The second is the use of spectral transfer methods, which require a small number of spectra to be collected on a daughter instrument in order to apply the parent model to spectra taken on daughter instruments. For this research, direct standardization algorithms were used to create spectral transfer matrices that corrected each spectrum taken on the daughter spectrometers. This allowed the use of the parent model on spectra taken on daughter instruments with 99 percent correct classification.

Lastly, robust testing of the model and calibration transfer methods were performed using blind tests and simulated real world samples. The blind testing used bottles of colors that exist in the data set as well as new bottles not in the original set. It was expected that the model would correctly classify colors that were already in the learning set, classify the new colors correctly by brand, and not classify any bottles that were from a brand not in the original learning set. Additionally, five colors from the collection were painted on acrylic nails for simulated real world experiments. A nail of each color was exposed to different environmental conditions and ATR-FTIR spectra were collected from the samples over time to see if degradation occurred and if the model could still correctly classify the samples.

This research proved that ATR-FTIR spectroscopy can detect very subtle differences between several nail polishes and gel samples that appear similar to the human eye. Chemometric models can be used to correctly classify replicates of various samples as a specific polish or gel, and calibration transfer methods can be used to apply models to new instruments and obtain the same results. The methodology behind this research has applications beyond nail polish, and calibration transfer methods can be very useful within the field of forensic science.

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Trace Isotope Analysis of Dental Enamel for Micro-Regional Geographic Attribution of Human Remains in Virginia

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This presentation highlighted the utility of trace element isotope ratios in dental enamel as a means of enhancing biological profiles, providing a method for the geographic attribution of birthplace and recent residence of unidentified human remains. Ultimately, this methodology could contribute to the compilation of a database of chemical isotope ratios by locality within Virginia, where there are currently approximately 165 cases of unidentified human remains in long-term storage in the four Virginia Offices of the Chief Medical Examiner (OCME) regions. In many of these cases, the remains are severely decomposed or skeletal and do not match any reports of missing persons, and fingerprints, DNA profiles, dental conditions, and facial approximations of these individuals have generated no leads in identification.

Dental enamel preserves well despite decomposition and holds promise for the expansion of new forensic identification methods. The bulk enamel composition ceases to change appreciably after a certain age and is thus indicative of an individual's birthplace (or early childhood residence), while the surface enamel composition continues to change, due to surface ion exchange and diffusion, and is indicative of an individual's recent residence (Molleson, 1988).

This study examined the bulk and surface enamel samples of approximately 90 teeth from 65 donors obtained from the Mission of Mercy and the Remote Area Medical Projects in Wise County, Grundy, Warsaw, and Emporia, Virginia, with approval from the Virginia Commonwealth University Institutional Review Board. Patients scheduled for an extraction were approached by a researcher and asked for written informed consent; if consent was provided, the patient was asked questions concerning age, sex, city and state of birth, and city and state of residence. Individuals in this study, who were born and currently reside in Virginia, had a donor age range of 21 to 70 years. The average donor age was 46.9 years, with an average donor age of 48 years for 36 females, and an average donor age of 45.4 years for 29 males. These locations were selected to expand on a pool of 74 samples from 52 donors' previously compiled samples, predominately from central and northern Virginia, collected from the Virginia Commonwealth University emergency dental clinic in Richmond (Stein, Ehrhardt, Hankle, & Simmons, 2017).

After extraction, samples were disinfected in 10 percent neutral buffered formalin for two weeks. Surface enamel was etched directly using a trace metal-free nitric acid and glycerin solution, while bulk enamel was dissolved in trace metal-free nitric acid after the enamel was ground into a fine powder using a mortar and pestle. Samples were analyzed for the following trace elements via inductively coupled plasma mass spectrometry (ICP-MS): ^{7}Li, ^{11}B, ^{25,26}Mg, ^{27}Al, ^{52}Cr 3+, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{58,60}Ni, ^{63,65}Cu, ^{64,66,68}Zn, ^{69,71}Ga, ^{78}Se, ^{86,87,88}Sr, ^{204,206,207,208}Pb, ^{209}Bi. Principal component analysis and discriminant function analysis were performed to examine multivariate relationships among samples and determine which trace elements drove compositional differences among the samples and the locality groups.

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The results from a one-way analysis of similarities yielded significant differences ($p \leq 0.00420$) between bulk and surface enamel ratios of individuals by geographic locality. Tooth characteristics (e.g., restorations, caries, debris, discoloration, chipping, cracking, and occlusal wear) did not significantly affect the isotope ratios of either the surface or the bulk enamel. This suggests that geographic determinations based on the isotope ratios of bulk and surface enamel are most likely neither influenced nor obscured by the tooth type and/or tooth characteristics. Significant correlations were found for bulk enamel ratios with the geographic location of an individual's birthplace and for surface enamel ratios with recent residence.

In conclusion, trace isotope ratios are useful in determining where individuals were born and currently reside, adding information to the biological profiles of unidentified remains and generating additional leads in the identification of these individuals.

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Identifying Human-Touched Objects Suitable for Microbiome-Based Forensic Applications: Reverse Fingerprint Lifting

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Latent fingerprint lifting has been carried out on objects to identify and classify human-touched objects within a workplace. This can be readily applied to both traditional (fingerprint analysis) and microbiome-based forensic identification. Several workplace objects such as a keyboard, mouse, phone, doorknob, stapler, and cabinet handle have been used for the study. Dusting the print in an office set-up is not advisable, due to the possibility of fine microscopic dust particles moving around the whole area. Secondly, dusting may disturb microbiome-based forensic analysis. Attempts have been made at reverse lifting—lifting the print and then developing it through dust lifting and chemical methods. Alternate light source (ALS) has been used to enhance the observation and to locate the latent print. Visible fingerprints are photographed and traditional methods of dusting with suitable powders have been used to lift the print. The method seems to work well with glazed/smooth surfaces.

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Interdisciplinary

Methods to Identify Gunshot Residue (GSR) Pattern Evidence on Decomposed Skin

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Gunshot residue (GSR) powder patterns can be useful in forensic cases because they can be used in shooting reconstruction in firearm-related incidents. When a firearm is discharged at an intermediate range-of-fire, a GSR powder pattern is typically observed on the target substrate. When the substrate is live skin, a specific type of powder pattern, powder stippling, can result when partially consumed and unconsumed gunpowder kernels impact live skin and result in small, punctate abrasions that cannot be wiped off the surface of the skin. In some instances, the gunpowder kernels can become embedded in the tissue, which may be referred to as "powder tattooing." In this discussion, the collective phenomena of punctate abrasions and kernel embedding following intermediate range-of-fire will both be referred to as simply "powder stippling." If the GSR powder patterns are of sufficient quality, these patterns can be visualized with various methods to indicate the use of a firearm on the substrate. The preservation, condition, and persistence of these patterns, though, are dependent on a variety of factors. In particular, decomposition is a dynamic, complex process that can potentially alter any physical evidence, such as GSR, present on the body; however, there is little information available on how decomposition could impact the condition of such powder patterns over time.

In this pilot study, the effect of decomposition on the persistence of GSR powder patterns was investigated on two animal models, and different methods were evaluated to identify GSR on the two target substrates. Two types of animal skin were shot with a firearm, subjected to decomposition under differing conditions, and assessed using different visual and chemical enhancement methods for the presence of GSR. In one experiment, fresh pig skin was shot using several combinations of handguns and ammunition to produce GSR powder patterns; skins were then subjected to decomposition fully exposed to the environment.

In the second experiment, two groups of five anesthetized live bull calves were clipped to remove hair from the target site, shot with a handgun at a distance of approximately two inches in an attempt to produce powder stippling patterns, and chemically euthanized. The calves were then subjected to decomposition either fully exposed, partially buried in soil, covered in vegetation, or sprayed with insect repellant. An eleventh calf was used as a negative control to illustrate the stages of decomposition of the bull calf model. The methods attempted to identify GSR on the animal skins included digital photography, stereo light microscopy, infrared photography, modified Griess test for nitrates, sodium rhodizonate test for lead, dithiooxamide test for copper, histology, and scanning electron microscopy.

Preliminary results of this pilot study indicate that the most appropriate methods to identify GSR on decomposed skin will depend on the stage of decomposition, condition of exposure, the type of skin, and the particular combination of firearm and ammunition used. For most instances, the sodium

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rhodizonate test appears to be the most useful and sensitive chemical method to identify GSR on decomposed skin. In particular, GSR has been indicated using this chemical method on pig skin that is several weeks decomposed. These experiments also indicate that powder stippling may be hindered if the target exhibits skin with considerable fur. Furthermore, visual observation of the bull calf decomposition trials has indicated that the presence of GSR may limit the insect activity around the entry wound. The experiments conducted are intended to serve as a pilot study. The trends that are indicated from the results can be used to direct more focused studies in GSR powder pattern and powder stippling investigations.

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Ontologies for a Situation-Based Framework for Identity in Crime Scenes

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Scope: This work is part of an effort to formulate a computational framework for identity that can be used in forensic and other contexts. Current work focuses on physical crime scenes, but the focus is expanding to cyberspace.

Objectives: The work reported here seeks to develop ontologies that provide the concepts required to capture the information relevant to identity judgments regarding a crime scene. We consider the crime scene as embedded in a case (in the legal sense) viewed as a constellation of situations. Semantic-web standards are used to express ontologies and encode cases in a way that supports queries and inferences.

Narrative

Introduction. Building a case to identify the culprit in a crime requires that one consider various sources of evidence and the situations out of which a case is constructed. The critical aspect is capturing the structure, which requires the appropriate trove of concepts. For this, we develop ontologies expressed in the Web Ontology Language (OWL).

Methods. This framework considers identity in terms of situations in the sense of Barwise's situation theory. A situation "supports" information. Situation types (abstract situations) can be tied to each other through "constraints," thus one situation may "carry" information about another as with, for example, the natural constraint by which smoke means fire. There are also conventional constraints governing speech by which an "utterance situation" "carries" information about a "described situation," and there may also be "resource situations" providing context. In the legal cases we consider, an identity judgment or id-situation is made as an utterance situation which carries information about the described situation, which in this case is the crime scene.

The framework uses semantic-web standards to store and analyze information supported or carried by situations. The concepts instantiated in the information are organized in several ontologies (conceptualizations of domains) expressed in OWL. The situations making up a case are encoded in RDF (Resource Description Framework) using the terms defined in the ontologies. Typically, certain information-bearing objects cross situations, thus stitching them together to form a case. Information handled in this way becomes "smart data" and supports not only extended queries but also inference. A reasoner infers RDF statements ("triples") from other triples and relations in an OWL ontology. OWL ontologies can be supplemented with rules in the Semantic Web Rule Language (SWRL). We use SWRL rules for drawing conclusions about the culprit in a crime scene and for classifying situations and constellations of situations.

Approaches. A typical scenario might have fingerprints and mugshots of the culprit and (to keep things simple) fingerprints and mugshots of the small set of suspects. The situations making up the case include not just the id-situation

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and the crime scene but also resource situations, for example, where the fingerprints and mugshots on file were taken and the fingerprint from the scene was lifted. The ontologies allow one to capture these situations and how they are structured to form a case. Our id-situation ontology focuses on situations and constellations of situations (i.e., id-cases) that involve id-judgments as well as any evidence supporting them. This ontology is built on the situation ontology and incorporates other ontologies that relate not only to the structure of a case but also to the specific kind of information, biometric artifacts, chains of custody, and procedures needed for evidence to support id-judgments. This includes the physical biometric ontology that addresses biometric artifacts (which has been our source of examples). These biometric artifacts are images of the suspects' physical features registered for use by forensic professionals. Consequently, for the information captured by physical biometrics, we have an extensive physical features ontology. This ontology relates specific surface features to specific persons, which allows the biometric images to serve as identifiers. Other ontologies used within the id-situation ontology include ontology stubs for personal records and for procedures for determining similarity of biometric images. Our law enforcement ontology recognizes various kinds of law enforcement agencies, law enforcement professionals, and suspects.

Future work. We are relating our ontologies to so-called upper ontologies, which provide the most general concepts, so that we may more easily align our ontologies with appropriate ontologies that have already been published. We are also elaborating our ontologies and developing new ones as we tackle new example cases. With help from the Criminal Justice Program at North Carolina A&T State University, we are producing a web page where students may scrutinize legal cases.

Attribution. What is presented here is based in large part on work by Marguerite McDaniel of the Computer Science Department of the University of Maryland, College Park, performed as part of Dr. Albert Esterline's research group in the Computer Science Department in the College of Engineering at North Carolina A&T State University. She will be unavailable in January 2018, and this is submitted with her permission.

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Handling Situation-Based Evidence in Identity Cases

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Scope: This work is part of an effort to formulate a computational framework for identity that can be used in forensic and other contexts. Current work focuses on physical crime scenes, but the focus is expanding to cyberspace.

Objectives: The work reported here seeks to capture how evidence in a case involving a crime scene conspires to support various identity judgments. Ontologies are being developed to capture a case as a constellation of situations where information is recorded or applied. Dempster-Shafer theory is being adapted to provide the framework for manipulating and combining information regarded as evidence.

Narrative

Introduction. The criminal justice system relies heavily on evidence, and Dempster-Shafer theory provides powerful mechanisms for determining what confidence one may have in evidence combined from several sources and possibly modified. There is considerable structure in a legal case that makes available information in which we may have various levels of confidence. We capture this structure using a family of ontologies, and we adapt Dempster-Shafer theory to exploit this structure.

Methods. This framework considers identity in terms of situations in the sense of Barwise's situation theory. A situation "supports" information. Situation types (abstract situations) can be tied to each other through "constraints," thus one situation may "carry" information about another as with, for example, the natural constraint by which smoke means fire. There are also conventional constraints governing speech by which an "utterance situation" "carries" information about a "described situation," and there may also be "resource situations" providing context. In the legal cases we consider, an identity judgment or id-situation is made as an utterance situation which carries information about the described situation, which in this case is the crime scene.

The framework uses semantic-web standards to store and analyze information supported or carried by situations. The concepts instantiated in the information are organized in several ontologies (conceptualizations of domains) expressed in OWL (Web Ontology Language). The situations making up a case are encoded in RDF (Resource Description Framework) using the terms defined in the ontologies. Typically, certain information-bearing objects cross situations, thus stitching them together to form a case. Information handled in this way becomes "smart data" and supports not only extended queries but also inference.

Dempster-Shafer theory distributes belief ("mass") to elements or sets of elements that are in a "frame of reference." Total mass sums to 1.0, with any unassigned mass going to the entire frame of reference. The "belief" that a given set A of elements covers what is the case is the sum of the masses of those sets that are included in A while the "plausibility" of A is the sum of the masses of the sets overlapping A. For any set A, belief and plausibility are between 0.0 and 1.0, and plausibility is never less than belief. Dempster-Shafer theory has various rules for combining mass functions when there are multiple sources of evidence,

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and there are various ways to manipulate mass functions and refine frames of discernment.

Approach. A typical scenario might have fingerprints and mugshots of the culprit and (to keep things simple) fingerprints and mugshots of the small set of suspects. The situations making up the case include not just the id-situation and the crime scene but also resource situations, for example, where the fingerprints and mugshots on file were taken and the fingerprint from the scene was lifted. The ontologies allow one to capture these situations and the evidence-relevant constraints among them. These constraints provide a structure for modifying and combining evidence as per Dempster-Shafer theory. The result is a framework that exposes the evidence-critical aspects of an entire case.

From a numerical point of view, there are three possible interpretations of constraints. One is that each situation or set of similar situations is a separate mass function and, therefore, when a constraint is in force, the mass function from the resource situation needs to be combined with the mass function from the id-situation. The second is to consider each resource situation as a refinement of the frame of discernment created in the id-situation. The third would be to consider the resource situation to be modifying the mass function.

Future work. With help from the Criminal Justice Program at North Carolina A&T State University, we are producing a web page where students may scrutinize how evidence from multiple sources is amplified or diminished and combined in support of an identification.

Attribution. What is presented here is based on work by Emma Sloan of the Computer Science Department of Brown University, performed as part of Dr. Albert Esterline's research group in the Computer Science Department in the College of Engineering at North Carolina A&T State University. Ms. Sloan will be out of the country in January 2018, and this is submitted with her permission.

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