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ICPUTRD: Image Cloud Platform for Use in Tagging and Research on Decomposition

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Final Report

Purpose and Objectives of the Project

There has been a concentrated movement within various research disciplines to focus on "Big Data". Contrary to its namesake, the big data movement is more concerned with the ability to "search, aggregate, and cross-reference large data sets" (Boyd and Crawford, 2012). Within biological, and subsequently, forensic anthropology, publicly available datasets that would be considered as big data are lacking. Particularly, there exists no freely available photographic database that includes multiple, daily, photographs of hundreds of human remains that chronicles the decomposition process from fresh to skeletal.

The Forensic Anthropology Center (FAC) at the University of Tennessee, Knoxville (UTK), is home to the Anthropology Research Facility (ARF), where, since 1981, human decomposition has been studied for a variety of purposes. Since 2012, multiple photographs of each donor (approximately 70 donors at any given time) have been processed daily. Daily photographs are taken for each donor from the time of possession until skeletonization. Each day, photographs are taken in accordance with set protocols (discussed below) with a scale bar. To date, the collection contains over a million of photographs from more than 400 donors.

To address the paucity of publicly available photographic databases documenting human decomposition process, the aims of the current proposal were three-fold: 1) develop a nomenclature of standard tags (labels) commonly used in medicolegal community to facilitate search and statistical modeling of human decomposition; 2) establish and implement an architecture for a collaborative platform for research on this very large collection of images; 3) evaluate the collaborative platform by implementing computer-assisted tagging of a very large set of images (the terms images and photographs are used interchangeably in this proposal).

The objective of the proposed research was to provide a searchable, user-friendly image collection annotated using forensics-relevant terminology and statistics to enable research collaboration for qualified forensic scientists. In particular, researchers were expected to be able to search the database for keywords from a standard nomenclature or metadata in this vast collection of images and to access data pertaining to their specific research questions. Furthermore, the project was proposing to annotate the collection with various features derived from the underlying images, and conduct basic data cleaning, such as identifying low quality or out-of-focus images.

Howe et al. (2008) pointed out that large datasets are paramount to further research in all biological sciences. As such, Howe et al. (2008) have outlined the following considerations for the biocuration of large datasets: 1) to connect information from multiple sources in a meaningful way; 2) to standardize nomenclature to make meaningful queries; 3) to ensure data quality upon entry; 4) to assist researchers with using the database; 5) incorporate cloud-based design; and 6) facilitate direct data submission. Given the aforementioned considerations, a platform to collaborate on a very large dataset documenting human decomposition would be of considerable value to forensic research.

In summary, the goals of the proposed research were three-fold: 1) develop a standard nomenclature for tagging images with keywords to facilitate meaningful searches; 2) establish and implement an architecture for a collaborative research on this rich collection of images; 3) evaluate the collaborative platform by implementing computer-assisted tagging of a large set of images. The primary goal of the project is to establish a cloud-based, easy-to-use collaborative image analysis and annotation platform for use by forensic researchers.

Project Design

The proposed research was divided into three components: 1) development of standard nomenclature for tagging photographs; 2) development and implementation of cloud-based collaboration platform architecture; 3) augmentation of the data by conducting computer-assisted large-scale tagging.

Nomenclature

The majority of the first research component involved amalgamation of widely acceptable terminology from the forensic literature on human decomposition. Some of the keywords are available in Table 1.

Table 1. The nomenclature for tagging.

Keyword	Observation Region(s)
Fresh	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Early Decomposition	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Advanced Decomposition	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Skeletonization	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Weight	Full body
Height	Full body
Sex	Donor sex

Maggots	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Beetles	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Larvae	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Bloat	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Purge	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Mummification	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Discoloration	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Wet	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Dry	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Scavenging	Head/neck, trunk, upper arms, lower arms, hands, upper legs, lower legs, feet, stomach, genitals
Total Body Score	Full Body, head/neck, trunk, limbs
Season	Full body
Average Daily Temperature	Full body
Month Start Date	Full body

Input data

Each photograph was taken in accordance with established protocols at the FAC. The exact procedure for taking daily photographs and for the curation of the photographs is very detailed and was outlined in Appendix II of the original project proposal. The camera is set to 2464 x 1632 resolution and photographs are taken from two sides of the body, as well as from above, using stadia rods as scales placed alongside and across (at head or feet) for each photo sequence. The scales and color section contrasts are included when forming a photo frame. The daily photo sequences include an overview, three sections of a body: head to shoulders, shoulders through pelvis, and pelvis to feet, and also an overview and details of arms and legs. Furthermore, a photo of a lateral view of the trunk is also taken to track the extent of bloat.

Photos were stored in a designated folder and the names of sub-folders and file names determine the assigned donor ID as well as the date when the photo was taken as described in Appendix II. The database also contained various metadata associated with each donor.

Collaboration Environment

The aim of this task was to create the collaboration platform for this large collection of images and make it available for search and analysis by other researchers and forensic practitioners. We obtained a storage area to store the images in a database, implemented an Application Programming Interface (API) to add and retrieve images and metadata, implemented basic search capabilities that involve the ability to retrieve images by individual, date, and the part of the remains that is represented by the image, and an API to add additional data, such as standard nomenclature tags or other annotations. Finally, as described in the Objective 3 below, this platform was used to create nomenclature tagging application that, based on experimental criteria, presents images to expert taggers.

We used open source architectural elements that are typical for cloud-based big data systems. The MongoDB database has a very flexible schema, good performance, and allows native storage of web data format JSON (Dede et al, 2013). We used MongoDB to store raw images, tags, image registration parameters and other textual and numeric data natively and use GridFS for very large files, such as stitched images and movies.

The user interface was provided using standard framework via AngularJS, Darwin & Kozlowski (2013). The back end uses Express framework (Ihrig, 2013) for simple search functionality and involves numeric and textual metadata. Text search was done using built-in functionality of MongoDB. In addition, we use Docker containers (Merkel, 2014) to simplify deployment and Jupyter notebooks (Ragan-Kelley et al 2014) for reproducibility. R language (Team R, 2000) and Python language engines for Jupyter notebooks were used to allow more traditional statistical analysis and to enable more complicated research tasks, including the development of new or improved image analysis techniques, the implementation of additional feature extraction and search capabilities and other functionality common for research tasks investigating the decomposition process. This lightweight architecture is optimal both for prototyping and for making it easy to add new functionality. The encapsulation of the server functionality in a Docker container permits a scalable architecture both by being able to run multiple containers (horizontally) and by provide more RAM and more computing resources for each container (vertically). It also makes it easy to transfer some or all of the computation tasks to a cloud provider, such as Amazon Web Services. The source code and development tools are hosted on BitBucket.org/icputrd/platform.

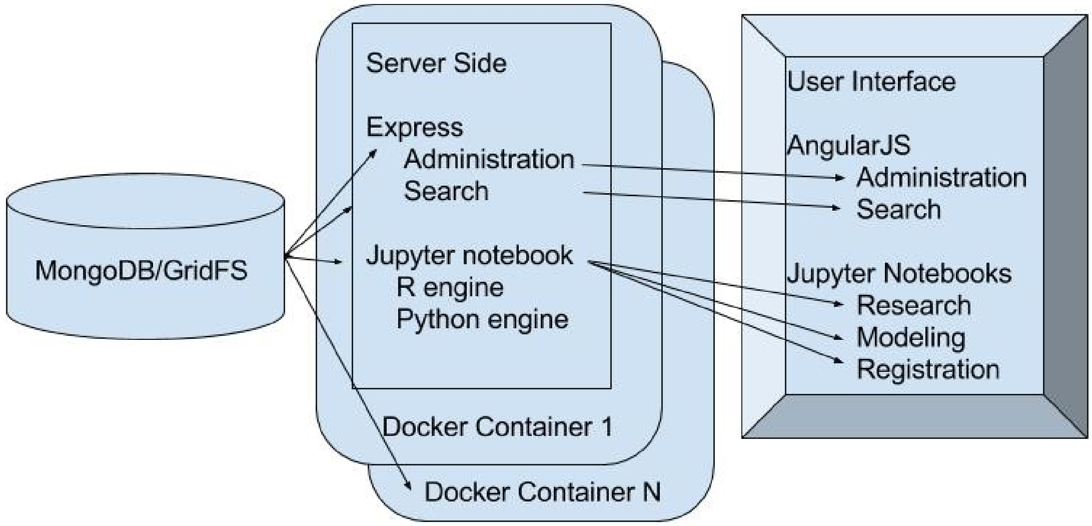

Figure 1. Architecture of the scalable cloud-based platform for the images and metadata.

During the implementation phase the collaboration platform was run on a server residing in restricted access server-room area of the Department of Electrical Engineering and Computer Science. The server runs Red Hat Server 7 OS with secure Linux and firewall enabled, thus limiting physical and network access to authorized individuals. In summary, the collaboration platform implemented the following use cases.

Importing a historic set of images for one year from the archival disk in the ARF collection

The user provides the location on the disk where the collection of images is uploaded as described in the user documentation at https://bitbucket.org/icputrd/platform/src/master/public/ICPUTRDDocumentation.pdf.

The program will then iterate over the set of donor IDs and over the set of daily images for each donor and perform the following steps

- Produces small versions (thumbnails) of each image
- Wraps each image in an html file to enable loading client-side JavaScript needed for annotation
- Creates html files showing indexes of images in each folder or groups of folders by selecting similar images from multiple folders.

Tagging the image with the nomenclature keywords.

The tagger selects an area of the image associated with each feature and then types the relevant tag. As the tag is typed, suggestions with valid tags are presented to the rater to minimize typos.

Once the tag is entered, a record in MongoDB associating the image with the selected tags is created and includes the date the tag was entered, and the identity (login) of the tagger.

String and numeric search based on nomenclature tags, donor characteristics, and dates. User will be presented with a search interface that includes a free text search box and the ability to create queries using fields including ranges of dates when the image was taken or when the donor was placed.

Flexible research functionality for creating/modifying registration and other techniques. The basic features of the platform will be accessible via REST APIs (Masse, 2011) and these APIs will be used to implement other services, like the tagging application described in the next component. In addition, more advanced users would be able to implement alternative registration methods and extraction of additional image features via Jupyter notebooks.

Tagging

Once the system was implemented the standard nomenclature derived in Objective 1 was applied to a very large set of strategically selected images. Tagging each of the photographs with meaningful keywords should facilitate querying the database, thus fulfilling the first three considerations mentioned above by Howe and colleagues (2008). The tagging of photos, however, is manual and time-consuming. With over a million of images it would not be feasible to tag every image manually with the resources provided by this grant (even assuming it takes one minute to tag an image, the total amount of work to tag the entire collection manually would take more than eight person years working a full 40 hour work week). The tagging, therefore, was conducted in a computer-assisted and collaborative manner. More specifically, it proceed in three primary steps.

1) A set of criteria were developed to identify a small subset of donors and, for these donors, a subset of approximately one thousand images that are likely to cover a broad range of tags from the nomenclature. The experimental design selected images taken both in winter and in summer, images that taken at the early stages and at the late stages of decomposition based on the date of intake and the temperature profile since intake.
2) The resulting images were tagged by four experts (trained anthropology GRAs) using the annotation capabilities of the platform. The GRAs authenticate with (log into) the platform using their browser and select the specific tagging experiment.
3) Evaluate the computer-generated tags.

The nomenclature keywords that lead to low cross-rater reliability were refined to reach higher within and cross-rater reliability or discarded if sufficient reliability is not achieved. We anticipate the tagging and nomenclature effort to continue beyond the duration of this project and to represent one of the future collaboration efforts enabled by this project. The initial tagging effort also provided a basis to develop machine-learning techniques to automate tagging for the entire collection in excess of a million of images. This effort continues.

Results

In short, we have achieved the goals set out in the proposal:

1) We have designed and refined the nomenclature of forensic terms that apply to photographs of decomposition in the collection.
2) We have implemented and evaluated the collaborative platform for tagging images in the collection.
3) Four experts have tagged over 3000 images with over 20,000 tags
4) We have performed user evaluation of ICPUTRD that demonstrates its utility to forensic researchers.

Nomenclature

To accomplish our goal and objectives, we have annotated selected areas of over 3000 images with standard tags commonly used in medicolegal community. The procedure involved annotating a much smaller set of images initially, then discussing the resulting labels and using the revised nomenclature to annotate the remaining set of images.

In the next step, for each of the labels, a dictionary of synonyms was created to facilitate the search. It was done in the following manner:

1) Unique terms from all annotations were extracted.

2) For terms that were deemed to be equivalent, for example, egg mass, insect eggs, and eggs the list of synonyms was created as well as a standard annotation. For the given example "egg mass" and "insect eggs" we relabeled as "eggs" and for the term "eggs" two synonyms were created.

Collaborative platform

The platform was implemented as described in the design section. We have included certain improvements based on the user study described below. For example, to reduce typos, the search suggestions appear as the expert is typing the tag. While initially the selection area was restricted to rectangle, we updated the platform to allow for selecting areas via arbitrary polygons because many of the relevant forensic features tend to have irregular shapes.

Tagging

The tagging was done by four experts and over 3000 images were tagged with over 20,000 tags. The approach to train machine learning methods to automate the tagging has been making progress with accuracy steadily increasing.

Evaluation

To ensure that the implementation of ICPUTRD satisfies the requirements we followed and to investigate whether or not the target audience of forensic scientists finds the system acceptable for conducting several research tasks we designed and executed a user study. More specifically, we evaluate the performance, efficiency and usability of the online platform, as well as obtaining feedback for potential improvements. The user study involved four main steps: study design, recruitment of participants, execution of the study, and analysis of the results.

To evaluate the usability of the already implemented features, but even more importantly, to evaluate the scope of additional features needed to make ICPUTRD truly useful for forensic work involving human decomposition, we designed a user study that involved both simple and creative tasks. The first task attempted to gauge the effectiveness of the current implementation on a simple task of finding images related to specific tags. The purpose of the second task was to evaluate the range of keywords forensic anthropologist may be interested in and also to find out how the users respond if the desired search query returns an empty set of results. The aim of the third task was to evaluate how users can use the annotation functionality.

As noted earlier the purpose of the user study is to evaluate usability, performance, and effectiveness of the system while getting feedback from the users. To do so, we need to know the forensic backgrounds of the users, type of interactions that they have with the system, and their experiences from the interaction. In order to cover all these three aspects, we designed a pre-study survey to get a general idea about the background of the users, the study tasks that requires users to interact with the system, and a post-study survey to know about the users' experience from interacting with the system and performing the given tasks.

The participants of the study were recruited from the target population of ICPUTRD users: graduate students, teachers and staff at Forensic Anthropology Center, University of Tennessee. The target population of human decomposition experts is rather small which made the process of recruiting participants challenging and time consuming. The PIs advertised the study via email and during seminars. In total, we recruited 10 participants including one staff, one faculty member, and 7 Ph.D. and one MS students. The information extracted from the pre-study survey, shown in Figure 1, displays the familiarity level of the participants with human decomposition, forensic work, image databases and multimedia curation. As can be seen from the chart, all participants are knowledgeable in human decomposition and forensic work but are not experienced in working with image databases and multimedia curation.

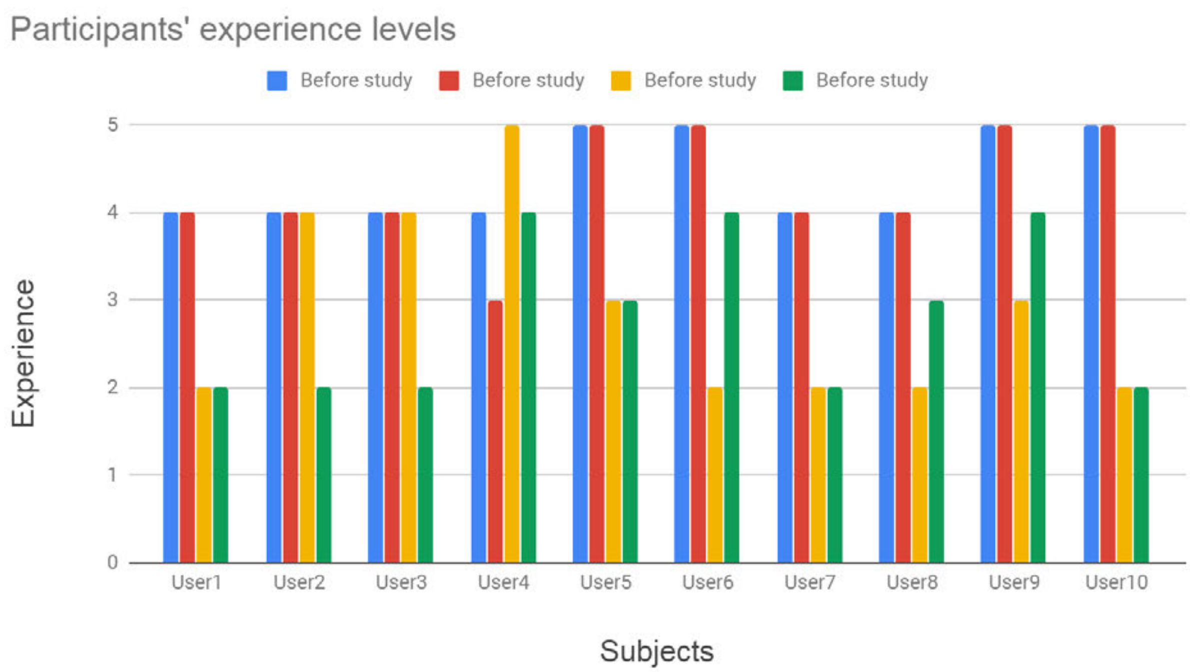

Figure 1: Experience level of subjects

Once participants were introduced to the system and the goals of the study, they were asked to read and sign the consent form and fill out the pre-study survey. The users were then instructed to interact with the system as described in provided tasks and ask questions in case of difficulties. One of the graduate research assistants also observed users while performing tasks and took notes on their comments and reactions. The overall time to conduct each user evaluation was estimated to be approximately 30 minutes. The exact instruction and tasks for the study were as follows.

1. "Find an example image using the keywords (up to 5 keywords)." For this task, we asked a domain expert to suggest a list of the tags that are qualified for this experiment. The list consisted of bloat, marbling, mummification, scavenging, slippage, post-bloat, maggots, maggot, skeletonization, lividity, mummified, flies, purge, adipocere, larvae. We then randomly selected a group of five tags from the provided list for each participant. The users were supposed to search for the images containing the provided keywords using ICPUTRD and explore the results. The main purpose of this task was to see if the users are able to use the basic features of the system. The post-study survey shows that all of the users we able to complete this task.

2. "Now try this yourself! Type in a keyword, different than the five you just used, that you might want to use for research with this photo collection." This task was similar to the previous task but had a different goal. The main purpose of this task was to learn if any keywords were missing from the current nomenclature and to determine what keywords that participants are most frequently interested in. The results of this step are used to improve the

nomenclature by adding the missing keywords and tagging a sample of photos with corresponding tags. Some of the users in the study selected only keywords from list provided by the system. This suggests that the the nomenclature that we designed was a sufficiently rich and provided terms most commonly used in this field. Some participants introduced new keywords, however. Specifically, **amputation, scattering, blister** and **pupae** were not in our existing nomenclature.

3. "Using this image, label five keywords that you see (you can include new keywords)." For this task all participants were shown the same full body picture. The purpose of this task was to determine if the users would be able to use image annotation capabilities and to see if different users would produce the same annotations. We found that for some tags, such as **larvae**, almost all of the users placed annotation in the similar area. The location of other tags varied substantially among participants, such as **purge**.

The interactions of each user with the system were recorded and the traces of these actions were associated with the usernames provided to them for the study. When the users were done with the tasks, they were asked to fill out the post-study survey that was used to determine any changes in in the participants' answers regarding their level of familiarity with the investigated domains and also to gauge their perceptions on difficulty of completing the given tasks. Figure 2 shows that there was no difference in forensic and human decomposition knowledge but there was a slight improvement in the understanding of multimedia curation for some of the participants. Figure 3 shows that the users were comfortable with completing the tasks.

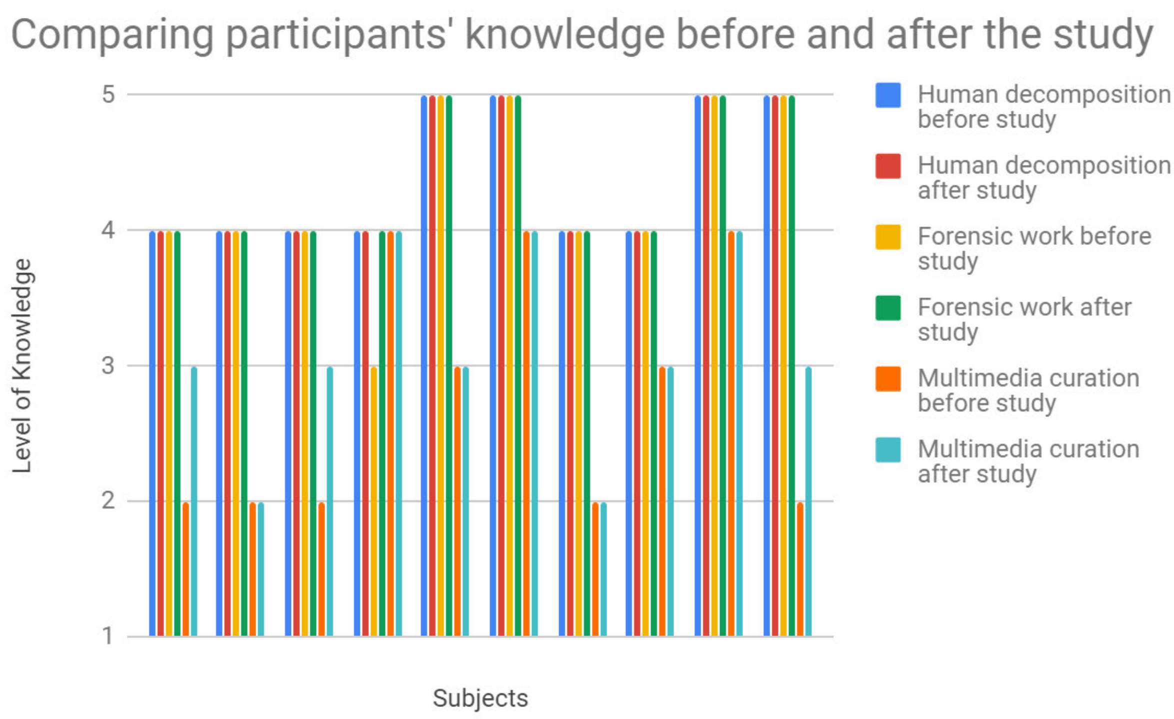

Figure 2: Pre- and post-study comparisons

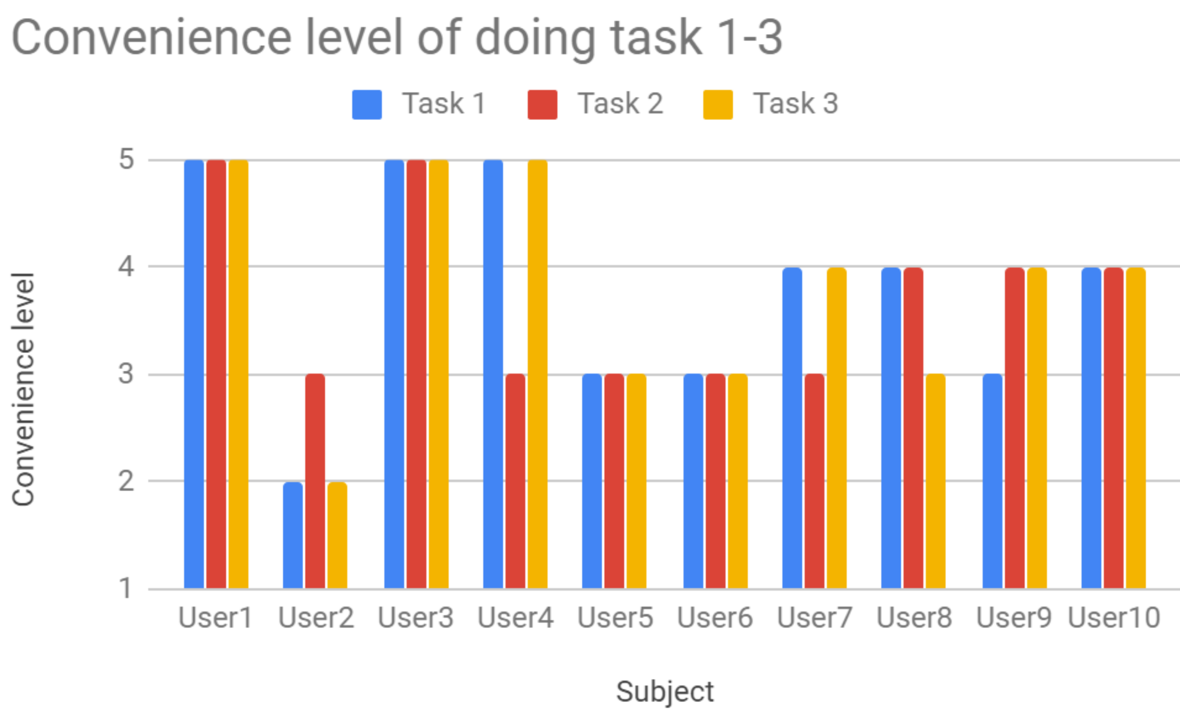

Figure 3: Task difficulty (5 - easy, 1 - difficult).

We calculated the correlation between the knowledge of the participants in different areas and how easy the tasks have been for them. Table 1 shows no correlation between familiarity level in human decomposition, forensic work, multimedia curation, image databases and the convenient level of the tasks. We can see that participants who are familiar with human decomposition were also knowledgeable in forensic work. Participants that were knowledgeable in forensic work didn't necessarily know multimedia curation. Participants that knew multimedia curation were also good at interacting with image databases.

Table 1: Correlation Matrix

	Human.decomposition.BS	Forensic.work.BS	Image.db.BS	Multimedia.curation.BS	convenient.t1	convenient.t2	convenient.t3
Human.decomposition.BS	1.0000000	0.8926074	-0.31282475	0.42146362	-0.45833333	-0.2090833	-0.25000000
Forensic.work.BS	0.8926074	1.0000000	-0.55347314	0.10748615	-0.54194021	-0.0199960	-0.38254603
Image.db.BS	-0.3128248	-0.5534731	1.00000000	0.19776638	0.07820619	-0.1594282	0.17596392
Multimedia.curation.BS	0.4214636	0.1074862	0.19776638	1.00000000	-0.16390252	-0.3818578	-0.04682929
convenient.t1	-0.4583333	-0.5419402	0.07820619	-0.16390252	1.00000000	0.5749792	0.89583333
convenient.t2	-0.2090833	-0.0199960	-0.15942822	-0.38185777	0.57497921	1.0000000	0.57497921
convenient.t3	-0.2500000	-0.3825460	0.17596392	-0.04682929	0.89583333	0.5749792	1.00000000

In summary, we found the usability of ICPUTRD to be adequate for the considered tasks, the nomenclature rich enough to cover most basic scenarios, and a subset of tags to be highly reproducible. At the same time, we discovered a number of needed improvements. First, we discovered several new tags researchers might use that are not included in the current nomenclature. Second, we found certain tags that are difficult for subjects to localize precisely. To address the first question, we will further study the necessity of adding the new tags to the nomenclature. To address the second shortcoming, we plan to enhance the system with the ability to select irregularly shaped areas associated with certain features, such as purge.

Implications for Criminal Justice Policy and Practice in the U.S.

Estimating decomposition events is central to forensic science and the criminal justice system in the United States. Previous research (Megyesi et al., 2005) has taken the requisite steps towards quantifying the decomposition process, though unaccounted for variability still remains. Applying big data approach for more than one million images collected in ARF is likely to dramatically increase the fidelity to the analysis and yield more accurate results. The results of our study have potential to directly impact the medicolegal community by providing opportunities to more precisely model the decomposition process, accounting for more sources of error (scavenging events, for example), and produce known error rates. The legal value of the evidence is increased when there are associated, quantifiable error rates (Christensen and Crowder 2009, Christensen 2004).

The proposed research provided a collaboration platform and a nomenclature of standardized forensic-related terminology that includes trait observations in layman's terms and cross-referenced it with thousands of images. The straightforward observation list is accessible to all practitioners regardless of experience or education level in evaluating decomposition through a simple web interface. This is especially important because the observed changes in human decomposition are highly qualitative and subjective. The collaboration platform provides a way to quantify the errors associated with assigning discrete traits based on a very large sample of observations. The collaborative platform with all of its source code is made available to the law enforcement and scientific communities and we have received strong interest and requests to help deploy it in other labs.

Scholarly Products

Conference Papers Presented:

- Audris Mockus, *Inverse Problems & Databases Bugs, Bodies, Decomposition and Statistics*, invited talk presented at Carnegie Melon University CSAFE Mini Symposium, December 13, 2016.
- Audris Mockus, *Curating Forensic Image Collection*, invited talk at Carnegie Melon University CSAFE Mini Symposium on September 11, 2017.

- Wangchen Yan, Audris Mockus, Tiffany B. Saul, Dawnie W. Steadman. *Curating forensic Image Collection Using Machine Learning*. Paper presented at the 70th Annual Meeting of the American Academy of Forensic Sciences, Seattle, WA, February 22, 2018.
- Sara Mousavi, Audris Mockus, Dawnie W. Steadman, Angela M. Dautartas. *Machine Learning to Detect and Localize Forensics-Relevant Features*. Paper presented at the 71st annual scientific meeting of the American Academy of Forensic Sciences, Baltimore, Maryland, February 22, 2019.
- Audris Mockus, *Image Cloud Platform for Use in Tagging and Research on Decompositio*n at the NIJ R&D symposium co-located with AAFS 2019.

Publications (Accepted and in Preparation):

- Mousavi, Sara and Nabati, Ramin and Kleeschulte, Megan, Steadman, Dawnie, and Mockus, Audris, *Machine-assisted annotation of forensic imagery*, Accepted at 26th IEEE International Conference on Image Processing (ICIP), Taipei, Taiwan, September 22-25, 2019.
- S. Mousavi, R. Hossain, A. Dautart , T. Saul, M. Kleeschulte, D. Steadman and A. Mockus. Open Curation of Forensic Databases, In preparation for the Journal of Forensic Sciences
- Dey, T., Mockus, A. 2018. A Matching Based Theoretical Framework for Estimating Probability of Causation.\arXiv e-prints arXiv:1808.04139. (preprint)

Software and documentation and other presentations:

- ICPUTRD platform source code and documentation: https:/bitbucket.org/icputrd/platform
- ICPUTRD platform tag development: https:/bitbucket.org/icputrd/tags
- A Software System to Support Tagging Large Collection of Images. Rayhan Hossain, Sara Mousavi, and Audris Mockus, Huawei Faculty Summit, Feb 23, Urbana-Champaign, IL
- Analyzing and Modeling Forensic Data Zachary Randall, Tasmia Rahman, Rosemary Dabbs, Sara Mousavi. Course project for CS545 Fundamentals of Digital Archeology.

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